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Water Consumption and Costs for Various Steam Electric Power Plant Cooling Systems

Cameron Engineers, Denver, Colo

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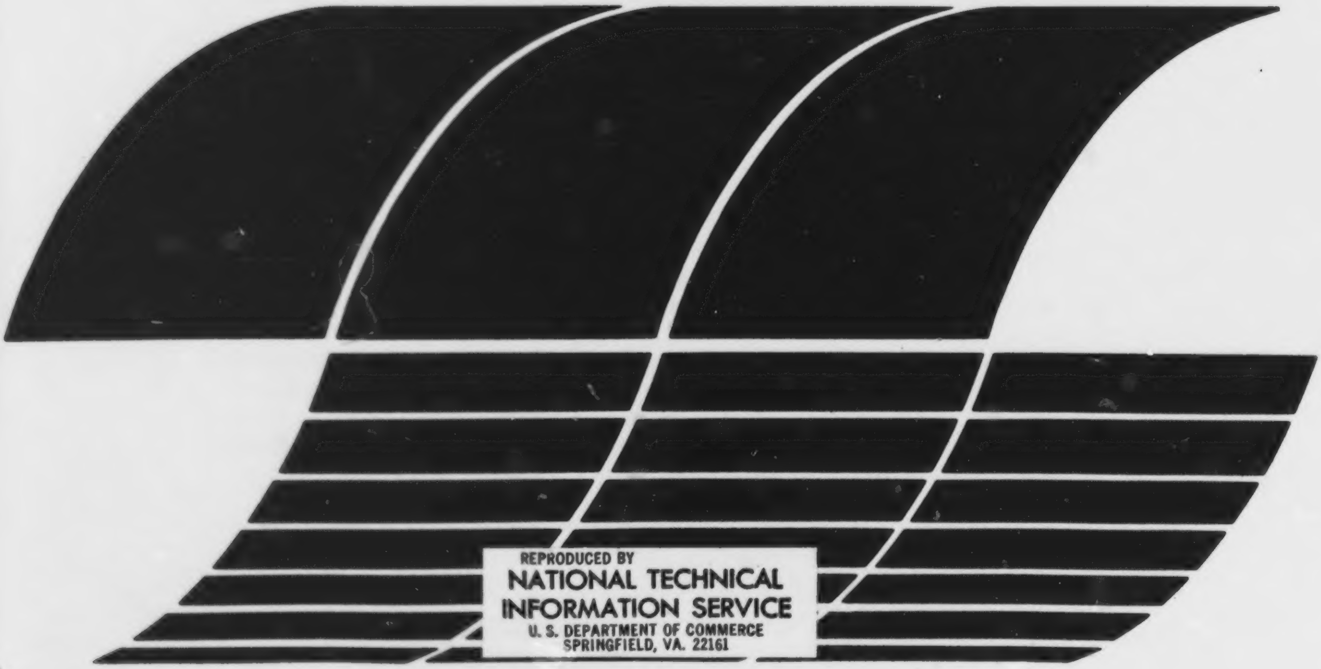

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16. ABSTRACT

The report gives results of a state-of-the-art study, addressing consumptive water use and related costs of various steam electric power plant cooling systems, the availability of water for all uses by area, and the impact of legal constraints on water use in the U.S. Evaporative losses for cooling systems were obtained from various sources, mostly post-1973 literature. Water availability data for all uses, especially power plants, were obtained primarily from a recent study by the U.S. Water Resources Council. Legal entities were reviewed to assess their impact on water use and consumption. Evaporative losses of cooling towers calculated with models were in general agreement. Forced evaporation losses for cooling ponds, based on the Brady and Harbeck models, differed by as much as 50%; the latter gave lower values. For moderate-to-large plants with inverse thermal loadings of 1 to 2 acres/MWe, Brady model results are more representative than the Harbeck values, since the latter are based on high inverse thermal loading. No discernible trend was found for capital costs of cooling systems by region; overlapping costs for various systems were evident in many regions. Varied constraints on water use and availability are not amenable to a simple operational classification.

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a. DESCRIPTORS		b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group	
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Cooling Systems		Cooling Ponds	13A	12A
Cooling Towers		Water Availability	07A/13I	
Water Consumption		Legal Restraints	02C	
Expenses		Brady Model	05C,14A	
Legislation		Hardbeck Model	05D	

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ABSTRACT

This state-of-the-art study reviewed and correlated available information on the following subjects: (a) the consumptive water use and the related costs of various open and closed cooling systems used by moderate and large capacity steam-electric generating stations in the United States, (b) the availability of water for all uses in the various areas of the U.S. and the percentage of water available that is used or projected to be used for steam-electric power plant cooling systems, and (c) the impact of regulatory guidelines on consumptive water use and its costs in the United States, especially for areas where water shortages exist or are projected to occur by the year 2000.

The information thus collected and correlated forms a part of an overall effort sponsored by EPA and is intended to provide the background information for the revision of the water pollution regulations for steam-electric power plants.

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Acknowledgments are due to D. Laura of the Water Resource Council. The water availability data presented in this report are based on the results of a recently completed four-year effort by the Council.

SECTION 1

INTRODUCTION

The objective of this study, under contract from the Environmental Protection Agency, was to collect, analyze and correlate available information on the following subjects: (a) the consumptive water use and the related costs of various open and closed cooling systems used by moderate and large capacity steam-electric generating stations in the United States, (b) the availability of water for all uses in the various areas of the U.S. and the percentage of water available that is used or projected to be used for steam-electric power plant cooling systems, and (c) the impact of regulatory guidelines on consumptive water use and its costs in the United States, especially for areas where water shortages exist or are projected to occur by the year 2000.

The results reflect an intense nine man-month effort performed in a three month period (October 1977 - January 1978) to complete a thorough state-of-the-art investigation. Due to the limitation of time and funding, omission of some of the available data is possible.

The information thus collected and correlated forms a part of an overall effort sponsored by EPA and is intended to provide backgound information for the revision of the water pollution regulations for steam-electric power plants.

Four tasks were performed to satisfy the requirements of this project. For each task, several subtasks were carried out to survey and select literature sources, to review and analyze the data collected, and to tabulate the relevant information.

SECTION 2

CONCLUSIONS

The conclusions of this study for each of the four major topics have been presented in Sections 5 through 8. These conclusions are summarized in this section according to the topics.

- Water Consumption for Various Cooling Alternatives

  1. There is a general agreement among the evaporation losses of cooling towers calculated with various models.

  2. There is a great discrepancy between the water consumption rates of cooling ponds calculated by EH&A using the Harbeck model and those calculated by HEDL using the Brady model.

  3. A definitive conclusion cannot be drawn as to which of the two (Harbeck and Brady et al.) models used to calculate the forced evaporation losses of cooling ponds gives more accurate results for lack of sufficient field data to verify the calculated results.

  4. Without due consideration of the actual cooling pond water surface temperature, the use of the Harbeck model for calculating the forced evaporation losses of cooling ponds may result in an underestimation of these losses. The assumption that the pond water surface temperature is equal to the average air temperature is not satisfactory for inverse thermal loadings such as 1 to 2 acres/MWe.

  5. The Brady model appears to result in more credible cooling pond forced evaporation losses because it considers the actual thermal loading of the pond in order to estimate the pond surface temperature.

- Related Costs of Alternate Cooling Systems

  1. It is difficult to compare the cost of alternative cooling systems solely on the basis of capital cost. The ranges of cost overlap for different cooling system alternatives.

2. There is no discernable trend of the capital cost of cooling systems by regions.

3. As expected, the total evaluated cost of once-through cooling is the lowest and that of dry cooling is the highest; other close-cycle conventional systems lie between these extremes.

4. The economic impact of the use of dry cooling to conserve water may be significantly reduced by the use of wet/dry cooling, but the economic penalty relative to wet cooling remains substantial.

o Water Availability for Steam-Electric and Other Uses

1. Under dry year conditions, there is not sufficient water in most regions of the conterminous United States to fully satisfy all users at their current rate of use. This situation is particularly critical in the Southwest and will become worse in the future.

2. Relative to the total consumption, the percentage consumption for steam electric generation was 1.23% in 1975 and will grow to 3.10% in 1985 and to 7.22% in the year 2000.

3. All segments of society which consume water must develop a water conservation strategy and implement that strategy. Since agriculture consumes the largest quantity of water by comparison with other water users, substantial water savings can be accomplished even with small percentage reductions in agricultural use through better utilization of the water resources. Conversely, a large percentage reduction in the consumption for steam electric generation is small by comparison.

o Regulatory Guidelines and Their Impact on Consumptive Water Use

1. There is no simple way to set down all the differing laws and accompanying rules and regulations, since they vary from state to state and are at the bottomline subject to decisions of the courts. An attempt was made to show the constraints on the legal availability of water. These constraints form a complex web which involves Federal rights, Indian rights, State rights, riparian rights, appropriation rights, beneficial uses, international treaties and others. Disregard for or any attempt to abrogate these rights (or arrangements) is certain to meet with serious objections and will result in lengthly litigation.

2. The fact that no comprehensive body of law exists, either on the national or state level, on the regulation and consumptive use of water adds to the difficulties and quandary in understanding water rights. Present national and state laws and regulations need codification and, in some cases, need to be rewritten to meet societal needs.

SECTION 3

RECOMMENDATIONS

Based upon the results of this study, recommendations for each of the four major topics of this study are as follows:

- Water Consumption for Various Cooling Alternatives

  1. There is an urgent need to verify the calculated evaporation rates with additional field measurements at operating plants. The additional field data should be collected using consistent measurement techniques and over representative geographic areas.

  2. A detailed study should be undertaken to compare the models currently available for evaluating the evaporative losses of cooling ponds. The comparison should have the ultimate goal of defining a definitive model with general applicability and semi-empirical correlations identified on a region-by-region basis.

- Related Costs of Various Alternate Cooling Systems

  EPA should establish and maintain a historical data base on the capital, operating, and maintenance costs of various cooling alternatives as estimated in power plant applications and ultimately constructed and operated by utilities.

- Water Availability for Steam-Electric and Other Uses

  1. Conservation of water in agriculture should receive the highest priority in order that the water thus saved can be diverted to other essential users.

  2. In water-limited areas the Federal Government should provide economic incentives to farmers to minimize the agricultural water use.

3. There is great need for EPA to establish an information retrieval system which is capable of accurately determining and continuously revising the water availability for steam-electric generation and other essential uses in various water resources regions or hydrological units.

- Regulatory Guidelines and Their Impact on Consumptive Water Use

  1. EPA should require state water plans to include water quantity and quality elements. Many present laws fail to recognize a relationship between water quantity and water quality.

  2. There is a need to establish one agency with legislated authority to coordinate water quality planning on a national level and have review responsibility for state plans.

SECTION 4

PROJECT METHODOLOGY

To satisfy the objectives of this project, four tasks were performed. Determination of water consumption, including evaporative losses and blowdown for various cooling alternatives, was the first task. Compilation of costs related to various cooling alternatives, including currently developing technology to reduce water consumption, was the second task. The third task was to determine the water availability in the United States for all uses in general and for steam-electric power plant cooling systems in particular. The fourth task was to assess the impact of regulatory guidelines on consumptive water use and its cost in the United States.

For each of these tasks, several subtasks were carried out to survey and select literature sources, to review and analyze the data collected on a given subject, and to correlate the relevant information.

4.1 LITERATURE SURVEY AND SELECTION OF RELEVANT DATA SOURCES

To conduct an effective search of the literature, an effort was made to apply several searching techniques and investigate a variety of sources. Thus, literature searches were performed in both the manual and computer/data base search modes.

Mechanized or computer searches are available from several organizations that routinely review a selected body of literature and designate by descriptive words or phrases the significant features of each article or report. To utilize these systems, the key words or categories used for the several specific searches were:

1. Cooling towers (including specific types of cooling towers in relation to their water use and costs)
2. Cooling ponds (both man-made and natural)
3. Power plants (including fossil- and nuclear-fueled power plants, costs, water consumption, water needs and resources)
4. Water resources and use (including costs, from all sources and for various applications -- agricultural, industrial, municipal, energy, mining)

Following is a list of the data/base code name and suppliers through which files were accessed and searched:

1. "RECON"
U.S. Department of Energy
Technical Information Center
Oak Ridge National Laboratory
Oak Ridge, Tennessee 37830

2. "DIALOG"
Lockheed Missiles & Space Company, Inc.
Department 52-08/201
3251 Hanover Street
Palo Alto, California 94304

3. "ORBIT"
Systems Development Corporation
2500 Colorado Avenue
Santa Monica, California 90406

For the manual searching the following resources were accessed in-house (UE&C) and among the local resources in the Philadelphia area:

1. U.S. Government Reports Announcements (USGRA) - current bi-weekly index to all NTIS accessions
2. Monthly Catalog of U.S. Government Publications
3. ERA - biweekly index to the U.S. Department of Energy, Technical Information Center accessions (also former Nuclear Science Abstracts - predecessor to ERA)
4. Applied Science and Technology Index
5. Science Citation Index
6. U.S. Environmental Protection Agency indexes

To supplement the mechanized and individual searches, the sources described above were used to identify publications that were surveyed, placing a particular emphasis on information which has evolved since 1973. The journals and magazines reviewed were:

1. Proceedings of the American Power Conference
2. Transactions of the American Society of Mechanical Engineers
    - Journal of Power
    - Journal of Heat Transfer
    - Journal of Fluids Engineering
3. American Institute of Chemical Engineers Journal
4. Proceedings of the American Society of Civil Engineers
    - Journal of the Power Division
    - Journal of the Hydraulics Division
    - Journal of the Water Resources Planning and Management Division
5. Environmental Science and Technology
6. Industrial Water Engineering
7. Power (magazine)
8. Power Engineering (magazine)

In reviewing the literature survey effort undertaken for this project and the relative contributions of each information source, the following general comments are applicable. First, the mechanized literature surveys were useful in the initial phase of a search as they required minimal expenditure of time and effort by the user of the service. The completeness of any mechanized search is dependent on the selection of key words that must be both precise and descriptive and on the scope of the data base by the organization compiling the computer files. The personal searches performed by the authors proved to be the most fruitful survey technique for this study. Personal contacts by phone with various authors contributed substantially to further identification of relevant literature sources.

4.2 DATA ACQUISITION

The literature search for information on the water consumption and costs for various steam-electric power plant cooling systems identified approximately 100 papers and reports published since 1973. Upon collecting all available in-house (UE&C) information, copies of other reports and papers were obtained from the technical libraries of the Philadelphia area or were solicited from the National Technical Information Service (NTIS) or directly from the authors. The EPA also provided copies of several reports on the consumptive water use for cooling ponds and cooling towers.

4.2.1 Water Consumption Data

Of all reports and papers identified for this subject, only two reports were found to contain a comprehensive treatment of the consumptive use of cooling systems for all of the 18 water resource regions (Figure 5.1) of the conterminous United States, namely References 1 and 2.

Since the results presented in the HEDL report were not directly comparable with the EH&A values, UE&C obtained from HEDL a copy of the original computer output from the consumptive water use algorithm from which the data given in the HEDL report were derived. These computer output data were further processed to meet the requirements of this project as shown in Section 5.

Several reports and papers were obtained directly from G. Earl Harbeck Jr., the author of the cooling pond consumption model used in the EH&A report. Other scattered data from various sources on cooling tower consumption rates were also included.

4.2.2 Cost Data for Cooling Alternatives

A total of about 40 reports and papers were reviewed in detail in order to obtain cost data for the various cooling alternatives. Inasmuch as possible, information was compiled for the 18 water resource regions in the conterminous United States for both fossil and nuclear power plants. The cooling alternative costs include both capital and total evaluated costs. The total evaluated cost, which is the total cost of the cooling alternative, is used to compare various cooling systems.

4.2.3 Water Availability Data

The water availability data were extracted from the draft of a study, "The Nation's Water Resources, The Second National Assessment by the U.S. Water

Resources Council." The final report will soon be completed by the U.S. Water Resources Council (WRC). The study was accomplished by the cooperative activities of state, regional and Federal agencies under the overall direction of the WRC and was a 3½-year effort designed to identify and describe the Nation's severe water problems. In the study, the conterminous United States was subdivided into 18 water resource regions. Each region was further divided into aggregated subregions, or ASR's. The limits of the regions and the total 99 ASR's for the conterminous United States were loosely related to existing major river systems.

The water consumption and availability data needed for this task and taken from WRC's 1975 assessment were: (a) water consumption rates (public supply, agricultural, industrial and mining, and steam-electric), (b) total stream flows, (c) water imports and exports, and (d) maximum flow rates. The 1975 values as well as projections for the years 1985 and 2000 were compiled. In addition to the overall values for the 18 water resource regions, data were also extracted from the 1975 Assessment for the most water deficient ASR in each water resource region.

4.2.4 Data on the Impact of Legal Constraints on Water Consumption and Related Costs

The information compiled (laws, regulations, treaties and compacts) and examined on a broad basis for the impact of regulatory guidelines on water consumption and related costs was obtained from documents containing the legislation itself or from books that treat the broad aspects of both water and environmental laws. Selected references listed at the end of this section give the primary documents used in the compilation.

The data considered included the constitutional basis for water laws, some of the more important Federal statutes, international treaties and interstate compacts. The potential impact of Indian water rights, Federal water rights and state water law and policy is also included. Other institutional considerations not included but requiring consideration are relationships to on-going and completed water resource development plans of Federal agencies, state and regional agencies as well as the individual state laws and legal precedents for particular situations.

A table at the end of Section 8 gives on a regional (water resource regions) basis the major rivers in the conterminous United States, known compacts or treaties on those water bodies, minimum flow at the outflow point of certain rivers and how these treaties or compacts apportion water among the various states. For the complex compacts and treaties, the section of the document referring to the apportionment has a reference number.

4.3 BASES FOR DATA COMPARISON

Since the task of determining the water consumption and the related costs includes comparisons among various steam-electric cooling alternatives and literature sources, it was necessary to establish a common basis for comparison. The ground rules employed by Espey, Huston & Associates, Inc. in their 1977 report on water consumption(1) were considered adequate and were adopted in this study. These ground rules are as follows: A 1,000 MWe fossil-fueled steam-electric generating station will be built. The plant is assumed to operate at a thermal efficiency of 36 percent, yielding a heat rate of 9,480 Btu/kWh. With a 10 percent stack heat loss, the heat rejection rate of the plant is 5,119 Btu/kWh. Operating at 80 percent capacity factor, the plant would reject approximately 36 x 10^{12} Btu/yr.

All water consumption data used from the literature collected were adjusted to reflect these assumptions and were then expressed in million gallons per day (MGD).

SECTION 5

WATER CONSUMPTION FOR VARIOUS COOLING ALTERNATIVES

5.1 DEFINITIONS OF WATER CONSUMPTION AND USES

A distinction should be made between the amount of water withdrawn from the surface water resources for cooling purposes and the amount of water "consumed" as a result of the cooling process. For the purposes of this study, water consumption is defined as that portion of water removed from and not returned to the surface water resources of a given area as a consequence of the cooling system under consideration.

In addition to the open-cycle cooling system (once-through cooling), four closed-cycle cooling systems were analyzed in this study from the standpoint of water consumption. The systems considered were as follows:

1. Once-through cooling system
2. Multipurpose cooling pond or natural lake used in part for power plant cooling
3. Single purpose cooling pond used primarily for power plant cooling, with other uses being incidental to its construction
4. Wet mechanical-draft cooling tower
5. Wet mechanical-draft cooling tower with a make-up pond of one-year storage capacity

5.1.1 Water Budget Equation

In its most general form, the water budget of a closed-cycle cooling system for a steam-electric generation station can be expressed with the following equation(1):

$$V = R + P + M - (G + S + B + E + I), \text{ (volume/unit time)} \qquad (5.1)$$

where:

V = change in cooling water storage.
R = local runoff inflow.
P = precipitation impingement onto the cooling water surface.
M = make-up water.
G = net ground water movement (negative for inflow to pond).
S = uncontrolled releases, e.g., pond seepage, overflow, etc.
B = blowdown.

E = total (natural plus forced) evaporation.
I = miscellaneous inplant use.

Although several terms in Equation (5.1) are not applicable to some cooling systems, the equation is general in its application to common types of closed-cycle cooling systems. Even when applicable, some terms were found to be neglected by some investigators either for being small in magnitude or to make the water consumption evaluation more conservative. The assumptions used in the EH&A(1,2) and HEDL(3) reports which were analyzed in this study are given later in this section.

5.2 METHODOLOGY FOR EVAPORATIVE LOSS CALCULATIONS

The water consumption for various cooling system alternatives can be predicted with models simulating the behavior of cooling towers, cooling ponds, and once-through cooling systems. The evaporative loss part of the total consumption, and especially its forced evaporation component, is the term whose calculation differs greatly from system to system and, to a smaller degree, from report to report. In arriving at average annual consumption rates, some differences may also appear in the published data depending upon whether the meteorological data used were monthly averages or annual averages.

Following is a review of the models used for estimating evaporative losses for various cooling alternatives in the two reports(1,3) mentioned in Section 4 that provided the main body of the water consumption data analyzed in this study. A comparison of the basic assumptions made in these reports is given in Table 5.1.

5.2.1 Models Available and Description

5.2.1.1 Cooling Tower Models--

An evaporative or wet cooling tower is a device which cools hot water by heat exchange at the air-water interface. The process is primarily based on evaporation (latent heat of vaporization is absorbed by evaporating water from cooled liquid) with a small portion of sensible heat transfer. This particular type of cooling is widely used and its design is based on a well-defined technology.

Under most meteorological conditions, the exhaust air from the cooling tower is saturated. The physical processes involved in the operation of a wet cooling tower can be easily modeled to give accurate predictions of the evaporation rate.

Nomographs developed by Leung and Moore(4) are widely used to determine the evaporation rate for wet towers as a function of the heat rejected which is based upon wet bulb temperature, relative humidity, and elevation. These nomographs were used to calculate the evaporative losses given in the EH&A report(1). Average annual meteorological data were used for each of the 16 locations considered.

The evaporation rates given in the HEDL report(3) were determined by solving the Merkel's equation for tower performance using finite element techniques developed by Winiarski(5). These evaporation rates equal the air flow rates through the tower times the change in absolute humidity of the air flow.

5.2.1.2 Cooling Pond Models--

Cooling ponds are bodies of water, man-made or natural, that are used for dissipating waste heat from steam-electric generating stations. Heat dissipation from the pond surface is accomplished through evaporation (natural or forced), convection, conduction, and radiation. It is highly dependent upon local meteorological conditions (solar radiation, dry bulb temperature, relative humidity or wet bulb temperature or dew point, wind speed, and cloud cover).

Determination of the evaporative losses for a cooling pond is a considerably more complex task than in the case of a wet cooling tower. This is because quantitative estimates of water consumption for cooling ponds involve many parameters.

The technical literature on cooling ponds presents two methods for estimating water consumption as follows(6,7):

1. Energy Budget Method

It is a technique based on the first law of thermodynamics; accounts for all incoming, outgoing and stored energy at the pond surface layer; and enables the calculation of the energy available for evaporation.

As applied to a water body, this principle requires that the net influx of energy be balanced by an increase of energy stored in the water. The energy budget or balance for a pond may be expressed in terms of energy rates as follows(8):

$$\Delta B + \Delta E + \Delta H + \Delta W = C \tag{5.2}$$

where:

ΔB = increase in long wave thermal radiation emitted by the body of water.
ΔE = increase in the amount of energy used for evaporation.
ΔH = increase in the amount of energy conducted from the water surface to the atmosphere as sensible heat.
ΔW = increase in the amount of energy carried away by the evaporated water.
C = the amount of energy added to the cooling lake or pond by the power plant.

Equation (5.2) yields:

$$\frac{\Delta E}{C} = \frac{\Delta E}{\Delta B + \Delta E + \Delta H + \Delta W} \tag{5.3}$$

where:

$\Delta E/C$ = percentage of heat added to the lake or pond that is used in forced evaporation.

The amount of heat added to the lake or pond is known, and if the amount of energy used in forced evaporation is known, the actual volume of forced evaporation can be easily determined by dividing by the latent heat of evaporation and density of water.

2. Mass Transfer Method

The method is based on mass transfer theory (Law of Conservation of Matter). Evaporation from a water surface is treated as the turbulent transport of water in an overlying boundary layer of water vapor. All the models using this theory are quasi-empirical and the equations take the following form:

$$E = CA\ f(u)\ (e_s - e_a) \tag{5.4}$$

where:

E = evaporation rate, MGD.
C = conversion factor, 10^6 gal/BTU-acre/ft^2.
A = pond surface area, acres.
$f(u)$ = wind speed function, u is wind speed in mph.
e_s = vapor pressure of saturated air at pond water surface temperature, mm Hg.
e_a = vapor pressure in the ambient air, mm Hg.

The wind speed function is assumed to be of the form:

$$f(u) = a + bu + cu^2,\ (\text{BTU/ft}^2\text{-day-mm Hg}) \tag{5.5}$$

where:

a, b and c are wind speed function coefficients determined experimentally for the various models used.

The models used for calculating forced evaporation from ponds or lakes by EH&A(1) and HEDL(3) are as follows:

1. EH&A Report

The EH&A report(1) used the model developed by Harbeck(8) which is based on the energy budget concept. In deriving the model, Harbeck also used a simplified mass transfer equation to account for the evaporation and to eliminate the need for collecting field data. According to Harbeck, this approach would give a reasonably accurate estimate of $\Delta E/C$. The resulting model is represented by a nomograph and a basic assumption on water surface temperature. The nomograph (Figure 5.1) gives $\Delta E/C$ as a function of water surface temperature with wind speed as a parameter. In the Harbeck model, the water surface temperature is assumed equal to the air temperature above the water surface, and the two-meter wind speed is used. For wind speed measured at other heights, adjustments to the two-meter height can be obtained by the following formula:

$$u = u_z \, (6.56/z)^{0.3} \qquad (5.6)$$

where:

u = wind speed at two meters, mph.
u_z = recorded wind speed at height z, mph.
z = height of anemometer above ground at the measuring site, feet.

Ordinarily, water surface temperature data are not readily available. The assumption that the air temperature is approximately equal to the water surface temperature is usually acceptable according to Harbeck(8). On an annual basis in areas where ice cover does not occur, the average annual water surface temperature is usually slightly lower than the average annual air temperature because of the cooling effect of natural evaporation. The addition of heat by a power plant may cause the water surface temperature to more nearly equal the air temperature, unless the plant load is large relative to the size of the lake(8). If large air-water temperature differences exist, the procedure using Harbeck's nomograph becomes of questionable value because of probable errors in the conducted energy term of the energy budget equation.

In the EH&A report(1), the water surface temperature was taken to be equal to the average annual dry bulb temperature. The average annual wind speeds were adjusted to the two-meter height.

2. HEDL Report

The HEDL report(3) used the mass transfer method employing the model developed by Brady et al(9) in which the wind speed function used in Equation (5.4) is as follows:

$$f(u) = 70 + 0.7u^2, \ (\text{BTU/ft}^2\text{-day-mm Hg}) \qquad (5.7)$$

This equation was obtained by curve fitting of experimental data for wind speeds from 1 to about 16 mph(9).

The pond water temperature required to calculate e_s was determined by iteration using the equilibrium temperature concept. The method involves the use of a surface heat exchange coefficient which is a function of the average wind speed, the dew point, and pond water temperature.

In the HEDL report(3), this methodology was applied to two distinct hydrological models of cooling ponds which assume different water circulation patterns. They are referred to as the "completely mixed" and "slug-flow" cooling pond models.

On the basis of circulation pattern and temperature distribution, cooling ponds can be classified as completely mixed ponds and flow-through (or slug flow) ponds(10). Completely mixed ponds have an almost uniform surface temperature with the exception of a small region near the plant discharge, while the slug-flow ponds have a continuous temperature decay from the plant discharge to the plant intake.

5.2.1.3 Once-Through Cooling Models--

Once-through cooling systems use cooling water derived from natural water bodies such as rivers, streams, lakes, and oceans. The water is discharged at a point where there is limited possibility of warm water recirculation. The evaporative losses presented in this study for once-through cooling (Table 5.4) were taken from the HEDL report(3) and the 1974 EH&A report(2).

The HEDL report(3) used a simplified model assuming a non-stratified, one-dimensional temperature distribution. The temperature distribution varies longitudinally, decaying exponentially in the downstream direction and asymptotically approaches the background temperature of the water body. It was assumed that the ambient sink is at the equilibrium temperature and that the dissipation of thermal energy takes place over an area of 50 acres/MWe. To bracket the evaporative loss for once-through cooling systems, two cases were considered. First, no dilution of the heat effluent with sink waters occurs and second, the heated effluent is diluted by 80%. For each of the two mixing patterns, two cooling ranges (10 and 30° F) were considered.

The EH&A report(2) used the Harbeck model for calculating the once-through cooling evaporative losses.

5.2.2 Assumptions Used for Calculating Water Consumption Rates

The two reports that provided the main body of the water consumption rates analyzed in this study were identified in Section 4 as the EH&A Document No. 7775 (September 1977)(1) and HEDL-TME 76-82 (September 1976)(3). The assumptions used in these reports for calculating the consumptive water use for cooling towers and cooling ponds have been summarized and presented comparatively in Table 5.1. Although the detailed comparison of assumptions is shown in Table 5.1, the following general comments are applicable.

5.2.2.1 Cooling Towers--

1. The EH&A report presents consumption rates relevant to four different cases which correspond to cooling towers with or without make-up pond, both categories being further subdivided with respect to the handling of blowdown water (retained in an impoundment or returned to the water body). The size of the make-up pond was determined so that the pond storage capacity matches the annual consumption of the associated cooling towers with an average depth of 15 ft. The blowdown was taken as 25% of the evaporation losses, which is equivalent to 5 cycles of concentration and is consistent with the current practice for much of the United States.

2. The HEDL report presents the consumption rate only for the case of cooling towers without a make-up pond operating and with blowdown equal to 5% of evaporative losses, which is equivalent to 21 cycles of concentration. This assumption is not consistent with current practice as indicated above. However, for the case of the cooling tower with blowdown returned, the total water consumption is not affected by the blowdown percentage considered. To complete the comparison, UE&C calculated the consumption rates for the remaining three cases considered in the EH&A report using the same make-up pond assumptions and a 5% blowdown (see Table 5.4).

5.2.2.2 Cooling Ponds--

1. The EH&A report presents water consumption rates for two types of cooling ponds based on their use: single purpose and multipurpose ponds. The former refers to man-made reservoirs used primarily for power plant cooling, with other uses being incidental to its construction; and the latter refers to natural lakes or multipurpose cooling ponds used in part for power plant cooling. A further division of the single purpose ponds is made for two different thermal loadings: 1 acre/MWe and 2 acres/MWe.
2. The consumptive use algorithm used in the HEDL report for calculating cooling pond water consumption rates also considered both single purpose and multipurpose ponds. However, twelve cases were considered in total, six for each type of use. These cases were obtained by varying the type of pond (mixed flow and slug flow), the cooling range (10^{o}F and 30^{o}F), and the thermal loading (1 and 3 acres/MWt). The high and the low numbers of the set of 12 numbers generated for each location were given as the limits for the expected range of water consumption for cooling ponds. Since the results thus presented in the HEDL report do not explicitly give the consumption for single purpose and multipurpose ponds separately, these numbers could not be compared directly with the EH&A results. To enable a direct comparison, UE&C requested and obtained from HEDL the computer output from their consumptive use algorithm and further processed the results to obtain consumption ranges separately for single purpose and multipurpose ponds.
3. The EH&A report did not take full credit for the precipitation impingement onto the pond surface area. The fraction of the precipitation that would have been absorbed into the soil, had the man-made pond not been there, was not considered in the overall balance. This approach was contrary to that used by HEDL. The results for single purpose ponds adjusted from these two reports and presented in Table 5.4 did not correct this difference in precipitation credit.
4. The effect of runoff correction on the water consumption rates of single purpose ponds given in the HEDL report is shown in Table 5.5. The results calculated with runoff correction show a larger water consumption rate than those without runoff

average wind speed at that location. The forced evaporation losses thus calculated with the Brady (HEDL) model were tabulated side by side with the EH&A report (Harbeck model) numbers for multipurpose ponds; that is, consumption due only to forced evaporation as shown in Table 5.2. The newly calculated numbers are considerably higher than the EH&A report numbers. For example, the consumption rates for multipurpose ponds at Dallas, Texas are 8.38 MGD for 1 acre/MWe and 8.33 MGD for 2 acres/MWe compared to 5.55 MGD. The average wind speed at this location used in the Brady model is greater than the wind speed adjusted to two-meter height as required by the Harbeck model. For comparison purposes, the wind speed at two-meter height was also employed in the Brady model, resulting in a forced evaporation of 8.08 MGD which is less than 5% smaller than the initial value of 8.38 MGD.

The considerable differences between the results obtained with the two models may be, in part, due to the fact that the Harbeck model was developed on the basis of very small thermal loading of cooling ponds. For very small thermal loading, the assumption of the pond water surface temperature being equal to the air dry bulb temperature may be valid. However, Harbeck(8) states that if the differential between the water surface temperature and the average air temperature is greater than 5°F, the results obtained with his model would be questionable. The thermal loading corresponding to 1 acre/MWe considered in the EH&A Document No. 7775 is about 10 times larger than those existing in the Lake Colorado City and Lake Hefner tests which provided the data base for Harbeck's formulation(12). Thus, the use of the Harbeck model for cooling ponds with thermal loadings of 1 to 2 acres/MWe is questionable.

The EH&A study(1) did not give the water consumption of multipurpose ponds (i.e., forced evaporation losses) as a function of the thermal loading in acres/MWe because the Harbeck nomograph does not use the thermal loading as a parameter. When the consumption of single purpose ponds was determined in the EH&A study, the balance between the natural evaporation and a conservatively adjusted precipitation was determined as a function of the pond surface area (1000 acres or 2000 acres for a 1000 MWe plant) and then added to the forced evaporation losses determined previously for multipurpose ponds. It appears, therefore, that since the forced evaporation losses were determined with the Harbeck model for ponds with very small specific thermal loadings, or alternatively, with surface areas much larger than 1000 or 2000 acres for a 1000 MWe plant; the single purpose pond consumptive rates in the EH&A report are also considerably underestimated.

By comparison, the consumption rates due to forced evaporation calculated with the Brady model appear to be more acceptable from an engineering standpoint, because the model does account for the representative thermal loading of a pond. However, as was the case for the Harbeck model, the empirical correlations used in the Brady model also involve uncertainties in the results generated for the 18 regions of the conterminous United States because these correlations were formulated using experimental data collected in limited regions of the United States. The analytic determination of the average pond surface temperature used to evaluate the Dalton difference introduces one more uncertainty in the results. Partly to account for these inherent uncertainties of the Brady model, the HEDL study gave the cooling pond consumption rates in a range bracketed by high and low values resulting from a set of parametric cases.

5.3.3 Comparison of Adjusted HEDL Results and EH&A Results

Upon adjusting all water consumption data for consistency of units and ground rules, the results were tabulated separately for each cooling alternative considered, indicating the original source of the data. The tabulation was made for two representative locations within each of the 18 water resource regions of the conterminous United States, with the exception of one region (New England) where three locations were considered. Table 5.3 shows the water consumption values for evaporative cooling towers, while Table 5.4 presents water consumption values for cooling ponds and for once-through cooling. Table 5.3 also gives the average annual values of the natural evaporation and precipitation in inches per year for the 37 locations considered. These values were used in adjusting the HEDL data for multipurpose ponds to single purpose ponds. The natural evaporation values were taken from the data base of the HEDL report.

The precipitation data were taken from the 1976 Local Climatological Data Annual Summary(13) provided by NOAA's National Climatic Center in Asheville, North Carolina.

Figures 5.3 through 5.6 show graphical comparisons of the water consumption results presented in Tables 5.2 through 5.4, which contain data from other literature sources in addition to those taken from references 1 and 3. The 18 water resource regions are given in the abscissas of the diagrams numbered from 1 through 18. These numbers correspond to those associated with the water resource regions listed in Tables 5.2 through 5.4.

The following general observations can be made based on the tabulated results and graphical representations of consumptive water use data:

1. The cooling tower water consumption rates given in the EH&A report are consistently larger than those given in the HEDL report by about 5% to 15% (see Figures 5.2 and 5.3).
2. The cooling pond water consumption rates given in the EH&A report are consistently smaller than their counterparts given in the HEDL report by about 30% to 50% (see Figures 5.4 and 5.5).
3. The cooling tower water consumption rates given in the reports prepared by UE&C for ERDA(14) and EPA(15) are within or slightly above the range given in the HEDL report, but smaller than their counterparts in the EH&A report (see Figures 5.2 and 5.3).
4. The EH&A report shows that, in general, single purpose cooling ponds have lower water consumption rates than cooling towers. This report shows the same is true for multipurpose cooling ponds. However, the difference in consumption rates between the multipurpose pond and the cooling tower is greater.

5. The comparison between the water consumption rates of cooling towers and those of cooling ponds, as given in the HEDL report, does not allow a generalization for the entire conterminous United States as to which of the two cooling alternates has lower water consumption. This is because the consumption ranges given for these two cooling alternates overlap for almost all regions considered. In the case of the single purpose ponds, their water consumption exceeds considerably that of cooling towers for water regions 9 through 16, and also 18 (California).
6. The HEDL report results also show that in some regions, single purpose cooling ponds may lead to smaller consumption rates than multipurpose ponds. The single purpose pond data for which this situation is true were identified by an asterisk in Table 5.4. These reduced water consumption rates are due to the fact that at the location affected the precipitation exceeds the natural evaporation. It is recalled that the HEDL report took full credit for the precipitation impingement onto the pond surface, whereas the EH&A report took only partial credit.
7. The water consumption values calculated for once-through cooling systems in the 1974 EH&A report(2) are consistently lower than the lower limit of the range given in the HEDL report(3) (see Table 5.4).
8. The water consumption values calculated for once-through cooling systems in the 1974 EH&A report(2) are consistently higher than those given for multipurpose ponds in the 1977 EH&A report(1). In contrast, the results given in the HEDL report(3) show that the once-through cooling water consumption rates are consistently lower than those for multipurpose cooling ponds.

5.4 WATER CONSUMPTION FIELD DATA FOR COOLING TOWERS AND COOLING PONDS

In a concurrent effort sponsored by EPA and carried out by VERSAR, Inc., field data on water consumption rates for both cooling towers and cooling ponds were collected from several utilities. The results of this study were presented in a draft report to EPA(16). These water consumption data were adjusted in the present study according to the ground rules stated in Section 4.3, and are shown in Table 5.6.

However, a direct comparison of the field data with the calculated results cannot be made because of the following reasons:

1. Data presented in the VERSAR report are inconsistent.
2. Insufficient information existed with respect to:
    a. The accuracy and method utilized in obtaining the field data
    b. The type (multipurpose or single purpose) of cooling pond
    c. The cooling tower blowdown assumptions
    d. The consideration of precipitation, runoff, and

natural evaporation in the cooling pond data

3. Extensive extrapolations were needed to bring the data to the same base with the calculated results.

In addition to the aforementioned experimental data for cooling pond water consumption rates, the literature search conducted for the purpose of this study revealed only one published paper. This paper(17) discusses the cooling pond built for the Milton R. Young steam plant of the Minnkota Power Cooperative, Inc. This cooling pond was constructed in an arid region of North Dakota and, after two years of operation, it was established that the cooling system performance closely followed the theoretical predictions using the mass transfer method.

5.5 CONCLUSIONS

From the results of the collected technical literature and presented in this Section on consumptive water use of various condenser cooling alternatives, the following conclusions can be drawn.

1. There is a general agreement among the evaporation losses of cooling towers calculated with various models.
2. There is a great discrepancy between the water consumption rates of cooling ponds calculated by EH&A using the Harbeck model and those calculated by HEDL using the Brady model.
3. A definitive conclusion cannot be drawn as to which of the two (Harbeck and Brady et al) models used to calculate the forced evaporation losses of cooling ponds gives more accurate results, because the available field data are, in general, not conclusive.
4. Without due consideration of the actual cooling pond water surface temperature, the use of the Harbeck model for calculating the forced evaporation losses of cooling ponds may result in an underestimation of these losses. The assumption that the pond water surface temperature is equal to the average air temperature is not satisfactory for thermal loadings such as 0.5 to 1.0 acres/MWe.
5. The Brady model appears to result in more credible cooling pond forced evaporation losses because it considers the actual thermal loading of the pond in order to estimate the pond surface temperature.
6. Before more research is performed to refine these models using feedback from operating cooling ponds, the comparison of consumptive water use by ponds and lakes with that of cooling towers cannot be well defined.

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TABLE 5.1 ASSUMPTIONS USED FOR CALCULATING WATER CONSUMPTION OF COOLING TOWERS AND COOLING PONDS

	ESPEY, HUSTON & ASSOCIATES, INC.[1] (Document No. 7775, September 1977)		HANFORD ENGINEERING DEVELOPMENT LAB[3] (HEDL-TME 76-82, September 1976)	
	Cooling pond	Cooling tower	Cooling pond	Cooling tower
1. Forced Evaporation Model	Harbeck[8] (heat budget method)	Leung & Moore[4]	Brady, Graves & Geyer[9] (mass transfer analysis)	Merkel Equation[5]
2. Storage Volume	No change	N/A	No change	N/A
3. Seepage	Neglected	N/A	Neglected	N/A
4. Precipitation (P)	Included for single purpose pond only but adjusted downward by runoff rainfall ratio	N/A	Included without any correction for runoff	N/A
5. Natural Evaporation (EN)	Included for single purpose pond only; data taken from mean annual lake evaporation	N/A	Included for manmade (single purpose) pond only.	N/A
6. Forced Evaporation (EF)	Included	Included	Included	Included
7. Miscellaneous Plant Use Water	Neglected	Neglected	Neglected	Neglected
8. Ambient Conditions	Major city annual averages for dry bulb and wet bulb temperature and relative humidity in the region	Same as for cooling pond	Mean of monthly average temperatures	Same as for cooling pond
9. Wind Speed	Annual average wind speed adjusted to wind speed at 2 meters above water surface	N/A	Annual average	N/A
10. Blowdown (B)	Neglected	Case 1 = Neglected Case 2 = 25% of evaporation	5% of evaporative requirements	Same as for cooling pond
11. Pond Size	1 acre/MWe and 2 acres/MWe	N/A	1 acre/MWt and 3 acres/MWt	N/A
12. Water Surface Temperature	Same as average dry bulb temperature	N/A	Determined by iteration using the equilibrium temperature concept	N/A
13. Water Consumption (C) Equation Used	C = EN + EF - 1 (1-r) P (for single purpose pond) C = EF (for multipurpose pond)	C = EF + B (blowdown retained) C = EF (blowdown returned)	C = EN + EF - P (for single purpose pond) C = EF (for multipurpose pond)	C = EF + B (blowdown retained) C = EF (blowdown returned)
14. Cycles of Concentration/ Percent Blowdown	N/A	5/25% of evaporation loss	N/A	21/5% of evaporation loss
15. Capacity factor	80% for calculating heat rejected annually by a 1000 MWe fossil fuel plant	Same as for cooling pond	80% for calculating heat rejected annually by a 1000 MWe fossil fuel plant	Same as for cooling pond
16. Effect of Elevation on Water Consumption	Neglected	Considered	Neglected	Considered
17. Cooling Range	Not Specified	Not Specified	Considered for the slug flow pond model only	Not Specified

TABLE 5.2 COMPARISON OF FORCED EVAPORATION LOSSES CALCULATED WITH THE HARBECK AND BRADY MODELS

Water resources region	Location	Harbeck model(1) (EH&A data for multipurpose ponds) (MGD)	Brady model(*) (EH&A meteorological data used as input) (MGD)
1. New England	Concord, NH Bangor, ME	3.66	
2. Mid-Atlantic	Richmond, VA Philadelphia, PA	4.49	
3. South Atlantic-Gulf	Tampa, FL Atlanta, GA	5.43	8.72
4. Great Lakes	Detroit, MI Cleveland, OH		
5. Ohio	Columbus, OH Louisville, KY	4.01	7.96
6. Tennessee	Knoxville, TN Chattanooga, TN		
7. Upper Mississippi	Twin Cities, MN St. Louis, MO	4.01 4.61	8.04
8. Lower Mississippi	Jackson, MS New Orleans, LA	5.08	
9. Souris-Red-Rainy	Bismark, ND Duluth, MN	4.13	
10. Missouri	North Platte, NE Great Falls, MT	4.37 4.25	
11. Arkansas-White-Red	Tulsa, OK Garden City, KS		
12. Texas-Gulf	Dallas, TX Houston, TX	5.55	8.33 @ 2000 ac 8.38 @ 1000 ac
13. Rio Grande	Albuquerque, NM El Paso, TX	4.84	8.03
14. Upper Colorado	Farmington, NM Grand Junction, CO		
15. Lower Colorado	Phoenix, AZ Yuma, AZ		
16. Great Basin	Salt Lake City, UT Reno, NV	4.72	7.89
17. Pacific Northwest	Seattle, WA Portland, OR	4.61	7.55
18. California	Los Angles, CA	4.01	8.31

* Calculated by UE&C using the Brady model from Reference 3.

TABLE 5.3 CONSUMPTIVE WATER USE FOR COOLING TOWERS

		Without makeup pond (MGD)								
		Blowdown returned					Blowdown retained			
				HEDL[3]				HEDL[3]		
Water resource region	Location	EH&A[2] (1974)	EH&A[1] (1977)	Low	High	UE&C (14,18,19)	EH&A[1] (1977)	Low	High	UE&C (14,18,19)
1. New England	Boston, MA	7.91	8.51	6.73	7.77	7.56	10.64	7.07	8.16	7.94
	Concord, NH			6.77	7.81			7.10	8.20	
	Bangor, ME			6.24	7.58			6.54	7.96	
2. Mid-Atlantic	Richmond, VA	8.27	8.87	7.31	8.06		11.09	7.68	8.46	
	Philadelphia, PA			7.06	7.94	8.20		7.41	8.34	8.61
3. South Atlantic-Gulf	Tampa, FL	8.98	9.34	8.08	8.48		11.68	8.49	8.90	
	Atlanta, GA			7.85	8.35	8.26		8.24	8.77	8.67
4. Great Lakes	Detroit, MI	8.03		6.79	7.83			7.13	8.22	
	Cleveland, OH			6.90	7.88			7.24	8.28	
5. Ohio	Columbus, OH	8.50	8.75	7.01	7.93		10.94	7.36	8.32	
	Louisville, KY			7.27	8.06			7.63	8.46	
6. Tennessee	Knoxville, TN	8.62		7.40	8.10			7.77	8.50	
	Chattanooga, TN			7.49	8.13			7.86	8.54	
7. Upper Mississippi	Twin Cities, MN	8.27	8.39	6.44	7.66		10.49	6.76	8.04	
	St. Louis, MO		8.87	7.28	8.06		11.09	7.65	8.46	
8. Lower Mississippi	Jackson, MS	8.86	9.22	7.81	8.33		11.53	8.20	8.75	
	New Orleans, LA			7.92	8.38	8.64		8.31	8.80	9.07
9. Souris-Red-Rainy	Bismark, ND	7.79	8.51	6.46	7.67		10.64	6.79	8.05	
	Duluth, MN			6.26	7.59			6.57	7.97	
10. Missouri	N. Platte, NE	8.39	8.87	7.14	8.01		11.09	7.50	8.41	
	Great Falls, MT		8.75	6.74	7.78		10.94	7.07	8.17	
11. Arkansas-White-Red	Tulsa, OK	8.74		7.57	8.19			7.95	8.60	
	Garden City, KS			7.57	8.19			7.95	8.60	
12. Texas-Gulf	Dallas, TX	9.09	9.34	7.85	8.33		11.68	8.24	8.75	
	Houston, TX			7.91	8.40			8.31	8.82	
13. Rio Grande	Albuquerque, NM	8.98	9.34	7.48	8.10		11.68	7.86	8.51	
	El Paso, TX			8.02	8.41			8.42	8.83	
14. Upper Colorado	Farmington, NM	8.15		7.53	8.16	8.39		7.91	8.57	8.81
	Gr. Junction, CO			7.11	7.95			7.47	8.35	
15. Lower Colorado	Phoenix, AZ	8.98		8.21	8.58			8.62	9.00	
	Yuma, AZ			8.33	8.77			8.75	9.21	
16. Great Basin	S. Lake City, UT	8.50	8.99	6.88	7.84		11.24	7.22	8.24	
	Reno, NV			7.30	8.01			7.67	8.42	
17. Pacific Northwest	Seattle, WA	8.27	8.39	6.64	7.81		10.49	6.97	8.20	
	Portland, OR			6.77	7.84			7.11	8.23	
18. California	Los Angeles, CA	8.75	8.75	7.69	8.21		10.94	8.07	8.62	
	Sacramento, CA	9.10	9.10	7.45	8.08		11.38	7.82	8.49	

TABLE 5.3 (cont'd.)

Water resource region	Location	Natural evap. (in/yr)	Average precip. (in/yr)	With makeup pond (MGD)							
				Blowdown returned				Blowdown retained			
				EH&A(1) (1977)	HEDL(3) Low	HEDL(3) High	UE&C (14,18,19)	EH&A(1) (1977)	HEDL(3) Low	HEDL(3) High	UE&C (14,18,19)
1. New England	Boston, MA	29.64	42.52		6.25	7.21	7.02		6.56	7.57	7.37
	Concord, NH	32.26	36.17	8.97	6.62	7.64		11.21	6.95	8.02	
	Bangor, ME	30.37	40.80		5.88	7.14			6.17	7.50	
2. Mid-Atlantic	Richmond, VA	38.95	42.59	9.28	7.16	7.90		11.60	7.52	8.29	
	Philadelphia, PA	35.67	39.93		6.89	7.75	8.03		7.24	8.14	8.44
3. South Atlantic-Gulf	Tampa, FL	69.14	49.38	10.09	8.97	9.41		12.61	9.42	9.88	
	Atlanta, GA	56.58	48.34		8.21	8.73	8.64		8.62	9.17	9.07
4. Great Lakes	Detroit, MI	32.52	30.96		6.85	7.90			7.19	8.29	
	Cleveland, OH	33.57	34.99		6.85	7.82			7.19	8.21	
5. Ohio	Columbus, OH	35.86	37.01	9.13	6.97	7.88		11.41	7.31	8.27	
	Louisville, KY	40.14	43.11		7.15	7.93			7.51	8.32	
6. Tennessee	Knoxville, TN	39.81	46.18		7.14	7.81			7.50	8.20	
	Chattanooga, TN	42.70	51.92		7.11	7.71			7.46	8.10	
7. Upper Mississippi	Twin Cities, MN	39.00	25.94	8.83	6.91	8.22		11.04	7.25	8.63	
	St. Louis, MO	42.69	35.89	9.37	7.56	8.36		11.71	7.93	8.78	
8. Lower Mississippi	Jackson, MS	51.43	49.19	9.73	7.91	8.43		12.17	8.30	8.86	
	New Orleans, LA	42.69	56.77		7.30	7.72	7.96		7.67	8.11	8.36
9. Souris-Red-Rainy	Bismark, ND	37.02	16.16	9.39	7.21	8.56		11.74	7.57	8.99	
	Duluth, MN	30.31	30.18		6.26	7.60			6.58	7.98	
10. Missouri	N. Platte, NE	44.53	19.90	10.26	8.12	9.11		12.82	8.52	9.56	
	Great Falls, MT	36.89	14.99	9.71	7.56	8.73		12.14	7.94	9.16	
11. Arkansas-White-Red	Tulsa, OK	52.77	36.90		8.24	8.91			8.65	9.36	
	Garden City, KS	56.83	20.58		9.09	9.84			9.55	10.33	
12. Texas-Gulf	Dallas, TX	62.25	32.30	10.86	9.16	9.72		13.58	9.61	10.20	
	Houston, TX	57.74	48.19		8.33	8.85			8.75	9.29	
13. Rio Grande	Albuquerque, NM	57.15	7.77	12.16	9.53	10.32		15.20	10.01	10.84	
	El Paso, TX	73.61	7.77		10.95	11.49			11.50	12.06	
14. Upper Colorado	Farmington, NM	53.34	7.77		9.44	10.23	10.51		9.91	10.74	11.04
	Gr. Junction, CO	44.39	8.41		8.53	9.54			8.96	10.02	
15. Lower Colorado	Phoenix, AZ	78.07	7.05		11.45	11.97			12.02	12.56	
	Yuma, AZ	80.14	2.67		11.92	12.54			12.51	13.17	
16. Great Basin	S. Lake City, UT	40.27	15.17	9.93	7.84	8.93		12.42	8.23	9.38	
	Reno, NV	46.65	7.20		8.91	9.77			9.36	10.25	
17. Pacific Northwest	Seattle, WA	25.31	38.79	8.45	6.14	7.23		10.57	6.45	7.59	
	Portland, OR	32.01	37.61		6.56	7.60			6.89	7.98	
18. California	Los Angeles, CA	50.87	14.05	10.35	9.26	9.89		12.95	9.73	10.38	
	Sacramento, CA	53.90	17.22	11.03	8.97	9.73		13.80	9.42	10.21	

TABLE 5.4 CONSUMPTIVE WATER USE FOR COOLING PONDS AND ONCE-THROUGH COOLING

Water resource region	Location	Multipurpose (natural) pond (MGD)					Single purpose (manmade) pond (MGD)				Once-through cooling (MGD)		
		EH&A (1) (77)	HEDL (3)		Sonnichsen (11)		EH&A (1)		HEDL (3)		HEDL (3)		EH&A (2) (74)
			Low	High	Low	High	1 ac/MWe	2 ac/MWe	Low	High	Low	High	
1. New England	Boston, MA	3.66	5.73	7.21	5.99	7.78	5.10	4.38	1.81*	5.91*	5.49	6.34	4.97
	Concord, NH		5.84	7.34					2.84*	6.34*	5.60	6.47	
	Bangor, ME		5.35	6.88					2.39*	5.89*	5.04	5.93	
2. Mid-Atlantic	Richmond, VA	4.49	6.58	8.45			5.73	5.11	5.47*	8.07*	6.17	7.21	4.97
	Philadelphia, PA		6.24	8.00					3.82*	7.19*	5.86	6.86	
3. South Atlantic-Gulf	Tampa, FL	5.53	7.76	9.42			7.57	6.50	10.28	13.28	7.62	8.55	5.68
	Atlanta, GA		7.07	7.83					8.62	9.54	6.84	7.76	
4. Great Lakes	Detroit, MI		5.83	7.46					6.35	7.62	5.51	6.44	4.61
	Cleveland, OH		5.92	7.47					5.22*	7.23*	5.65	6.54	
5. Ohio	Columbus, OH	4.01	6.13	7.93			5.17	4.59	5.72*	7.78*	5.72	6.72	5.08
	Louisville, KY		6.46	8.24					5.73*	8.00*	6.09	7.10	
6. Tennessee	Knoxville, TN		6.61	8.61					4.38*	7.85*	6.13	7.21	5.32
	Chattanooga, TN		6.70	8.62					5.24*	8.12*	6.27	7.32	
7. Upper Mississippi	Twin Cities, MN	4.01	5.42	6.90			5.41	4.71	7.38	9.02	5.16	5.98	4.97
	St. Louis, MO	4.61	6.48	8.19			6.11	5.36	8.04	8.88	6.17	7.12	
8. Lower Mississippi	Jackson, MS	5.08	7.18	8.93			6.56	5.82	7.16*	8.90*	6.91	7.88	5.68
	New Orleans, LA		7.31	9.07					2.30*	7.40*	7.02	8.01	
9. Souris-Red-Rainy	Bismark, ND	4.13	5.25	6.69			6.89	5.51	8.10	11.59	4.99	5.79	4.37
	Duluth, MN		5.13	6.52					5.42	6.62	4.90	5.69	
10. Missouri	N. Platte, NE	4.37	6.05	7.66	6.51	8.12	8.55	6.46	9.48	13.90	5.79	6.65	4.97
	Great Falls, MT	4.25	5.43	7.00			7.19	5.72	8.59	12.31	5.10	6.00	
11. Arkansas-White-Red	Tulsa, OK		6.82	8.44					8.78	10.50	6.61	7.48	5.91
	Garden City, KS		6.48	7.89					10.71	17.85	6.40	7.42	
12. Texas-Gulf	Dallas, TX	5.55	7.14	8.65			9.89	7.72	10.65	16.16	7.06	8.11	6.38
	Houston, TX		7.42	9.04					9.78	12.51	7.28	8.18	
13. Rio Grande	Albuquerque, NM	4.84	6.26	8.07	7.39	9.31	12.90	8.87	11.30	18.27	5.87	6.86	5.79
	El Paso, TX		6.94	8.58					13.65	24.92	6.74	7.59	
14. Upper Colorado	Farmington, NM		6.25	8.06					11.44	18.68	5.86	6.86	4.49
	Gr. Junction, CO		6.00	7.82					9.80	14.17	5.62	6.53	
15. Lower Colorado	Phoenix, AZ		7.41	9.37					14.77	26.11	7.01	8.07	5.68
	Yuma, AZ		7.32	9.10					14.90	27.43	7.05	7.99	
16. Great Basin	S. Lake City, UT	4.72	5.55	7.35			7.52	6.12	8.80	11.92	5.11	6.09	4.85
	Reno, NV		6.07	8.12					11.11	17.11	5.53	6.62	
17. Pacific Northwest	Seattle, WA	4.61	5.85	7.79			4.81	4.71	1.20*	6.23*	5.34	6.41	4.49
	Portland, OR		6.07	7.99					-7.55*	3.45*	5.58	6.65	
18. California	Los Angeles, CA	4.01	6.96	8.90			8.91	6.46	11.28	16.47	6.52	7.62	5.32
	Sacramento, CA	4.61	6.69	8.45			10.29	7.45	10.05	13.98	6.37	7.33	

* Average precipitation exceeds natural evaporation

TABLE 5.5 EFFECT OF PRECIPITATION CREDIT ON WATER CONSUMPTION CALCULATED FOR SINGLE PURPOSE COOLING PONDS

Water resource region	Location	Precipitation, P (in/yr)	Run-off(1), R (in/yr)	Runoff(1) Coef., $r=\frac{R}{P}$	$(1-r)P^{(1)}$ (in/yr)	HEDL(3) model water consumption (MGD)				EH&A(1) model water consumption (MGD)	
						with runoff correction*		without runoff correction+			
						Low	High	Low	High	1 acre MWe	2 acres MWe
1. New England	Concord, NH	36.17	20.00	0.55	16.28	7.26	8.08	2.84	6.34	5.10	4.38
2. Mid-Atlantic	Richmond, VA	42.59	11.50	0.27	31.09	8.02	8.91	5.47	8.07	5.73	5.11
3. South Atlantic-Gulf	Tampa, FL	49.38	13.50	0.27	36.05	11.27	16.24	10.28	13.28	7.57	6.50
5. Ohio	Columbus, OH	37.01	12.00	0.32	25.17	8.21	9.11	5.72	7.78	5.17	4.59
7. Upper Mississippi	Twin Cities, MN St. Louis, MO	25.94 35.89	5.00 10.00	0.19 0.28	21.01 25.84	7.74 8.93	10.11 11.11	7.38 8.04	9.02 8.88	5.41 6.11	4.71 5.36
8. Lower Mississippi	Jackson, MS	49.19	15.00	0.30	34.43	9.44	11.34	7.16	8.90	6.56	5.82
9. Souris-Red-Rainy	Bismark, ND	16.16	0.75	0.05	15.35	8.15	11.76	8.10	11.59	6.89	5.51
10. Missouri	North Platte, NE Great Falls, MT	19.90 14.99	1.00 0.30	0.05 0.02	18.91 14.69	9.55 8.60	14.21 12.37	9.48 8.59	13.90 12.31	8.55 7.19	6.46 5.72
12. Texas-Gulf	Dallas, TX	32.30	4.50	0.14	27.78	10.97	17.16	10.65	16.16	9.89	7.72
13. Rio Grande	Albuquerque, NM	7.77	0.15	0.02	7.61	11.31	18.31	11.30	18.27	12.90	8.87
16. Great Basin	Salt Lake City, UT	15.17	0.20	0.01	15.02	8.81	11.95	8.80	11.92	7.52	6.12
17. Pacific Northwest	Seattle, WA	38.79	17.00	0.44	21.72	4.99	7.49	1.20	6.23	4.81	4.71
18. California	Los Angeles, CA Sacramento, CA	14.05 17.22	1.00 3.50	0.07 0.20	13.07 13.78	11.35 10.30	16.54 14.74	11.28 10.05	16.47 13.98	8.91 10.29	6.46 7.45

* $C = FE + NE - (1-r)P$
+ $C = FE + NE - P$

where: C = pond water consumption
FE = forced evaporation
NE = natural evaporation

TABLE 5.6 ADJUSTED FIELD DATA ON WATER CONSUMPTION OF COOLING TOWERS AND COOLING PONDS

Water resource region	Location	Steam electric station	Utility	Water consumption (MGD)	
				Cooling Pond	Cooling Tower
1. New England	Merrimack County, NH	Merrimack	Public Service of New Hampshire	13.42	---
7. Upper Mississippi	Pekin, IL	Powerton	Commonwealth Edison Co.	5.91	---
Upper Mississippi	Kincaid, IL	Kincaid	Commonwealth Edison Co.	21.30	---
Upper Mississippi	Fort Atkinson, WI	Koshkonong	Wisconsin Electric Power Co.	---	Data questionable
8. Lower Mississippi	Stamps, AR	Couch	Arkansas Power & Light Co.	---	6.52
Lower Mississippi	Forest City, AR	Moses	Arkansas Power & Light Co.	---	30.65
13. Rio Grande	Dona Ana County, NM	Rio Grande	El Paso Electric Co.	---	13.76
Rio Grande	El Paso, TX	Newman	El Paso Electric Co.	---	14.50*
14. Upper Colorado	Huntington, UT	Huntington	Utah Power & Light Co.	---	11.22*

* average for three units

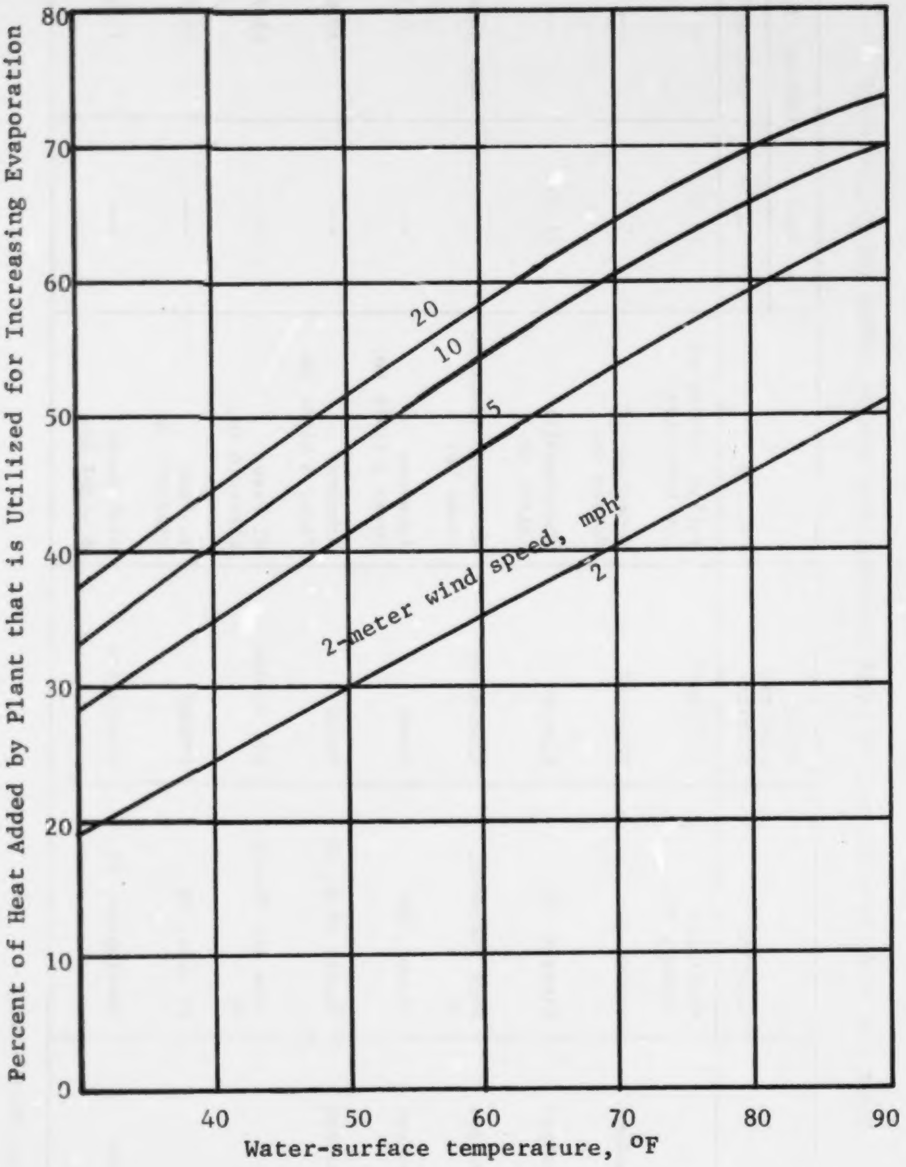
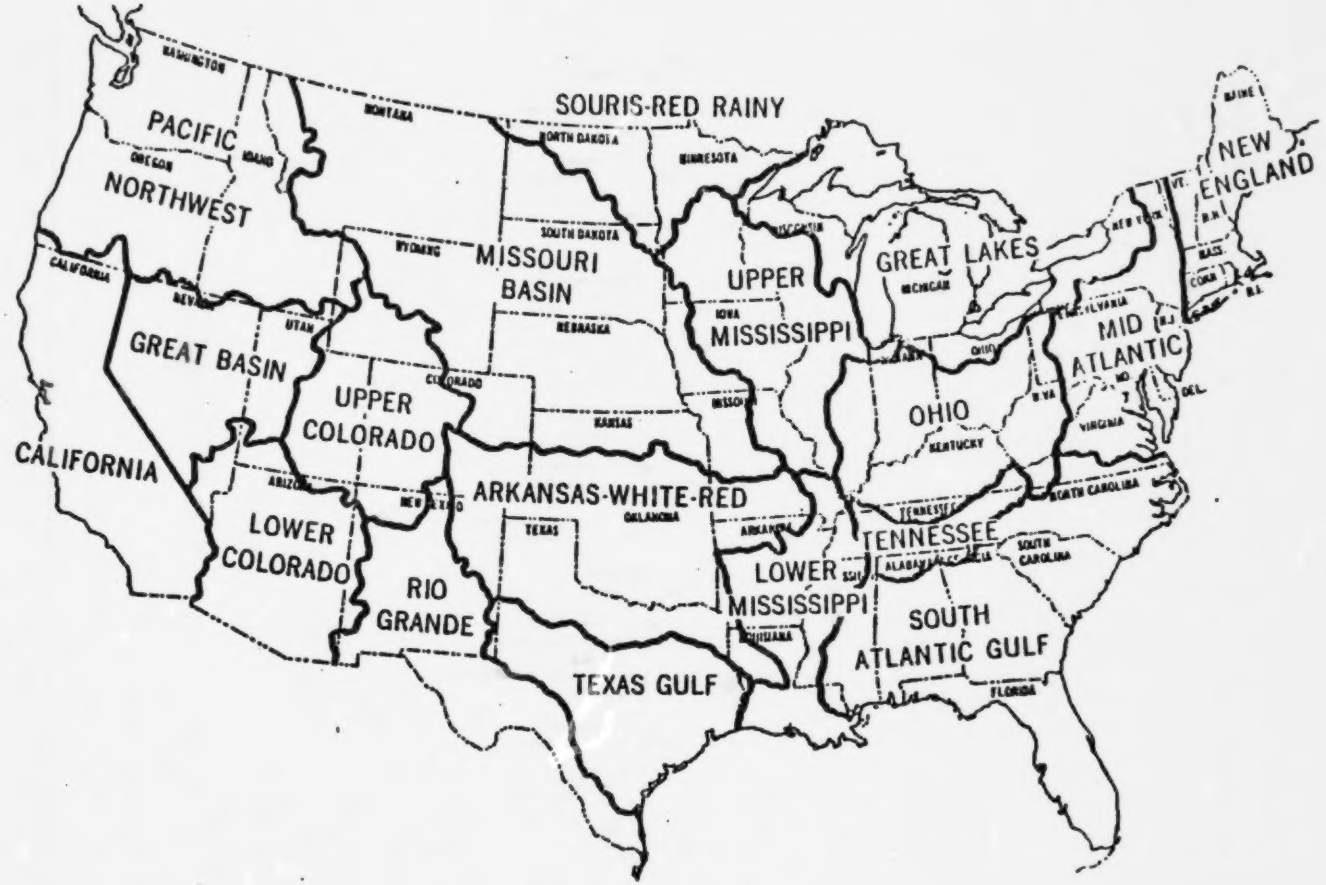


Figure 5.1 Estimating the Increase in Reservoir Evaporation Resulting from the Addition of Heat by a Power Plant (8)


SOURIS-RED RAINY
PACIFIC NORTHWEST
MISSOURI BASIN
UPPER MISSISSIPPI
GREAT LAKES
NEW ENGLAND
MID ATLANTIC
OHIO
GREAT BASIN
UPPER COLORADO
CALIFORNIA
ARKANSAS-WHITE-RED
TENNESSEE
LOWER COLORADO
RIO GRANDE
LOWER MISSISSIPPI
SOUTH ATLANTIC GULF
TEXAS GULF
WASHINGTON
MONTANA
NORTH DAKOTA
MINNESOTA
OREGON
IDAHO
SOUTH DAKOTA
WYOMING
CALIFORNIA
NEVADA
UTAH
NEBRASKA
MICHIGAN
IOWA
COLORADO
KANSAS
OHIO
KENTUCKY
VIRGINIA
ARIZONA
NEW MEXICO
OKLAHOMA
TEXAS
ARKANSAS
TENNESSEE
NORTH CAROLINA
SOUTH CAROLINA
ALABAMA
LOUISIANA
FLORIDA
MAINE
VT.
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R.I.
N.J.
MD.
DEL.

Figure 5.2 Map Showing Water Resource Regions Defined by Water Resources Council(1)

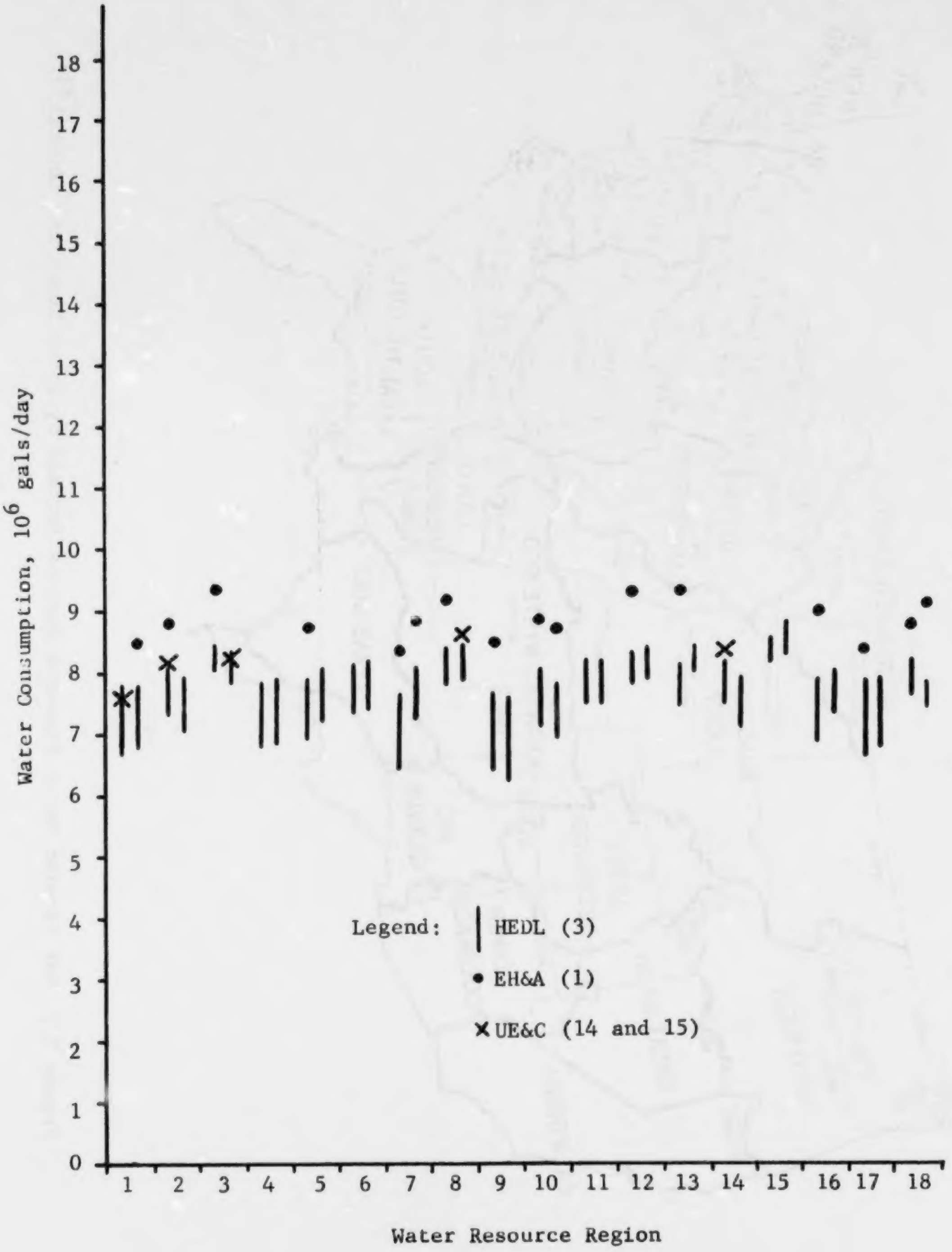

Figure 5.3 Cooling Towers Without Makeup Pond (Blowdown Returned)

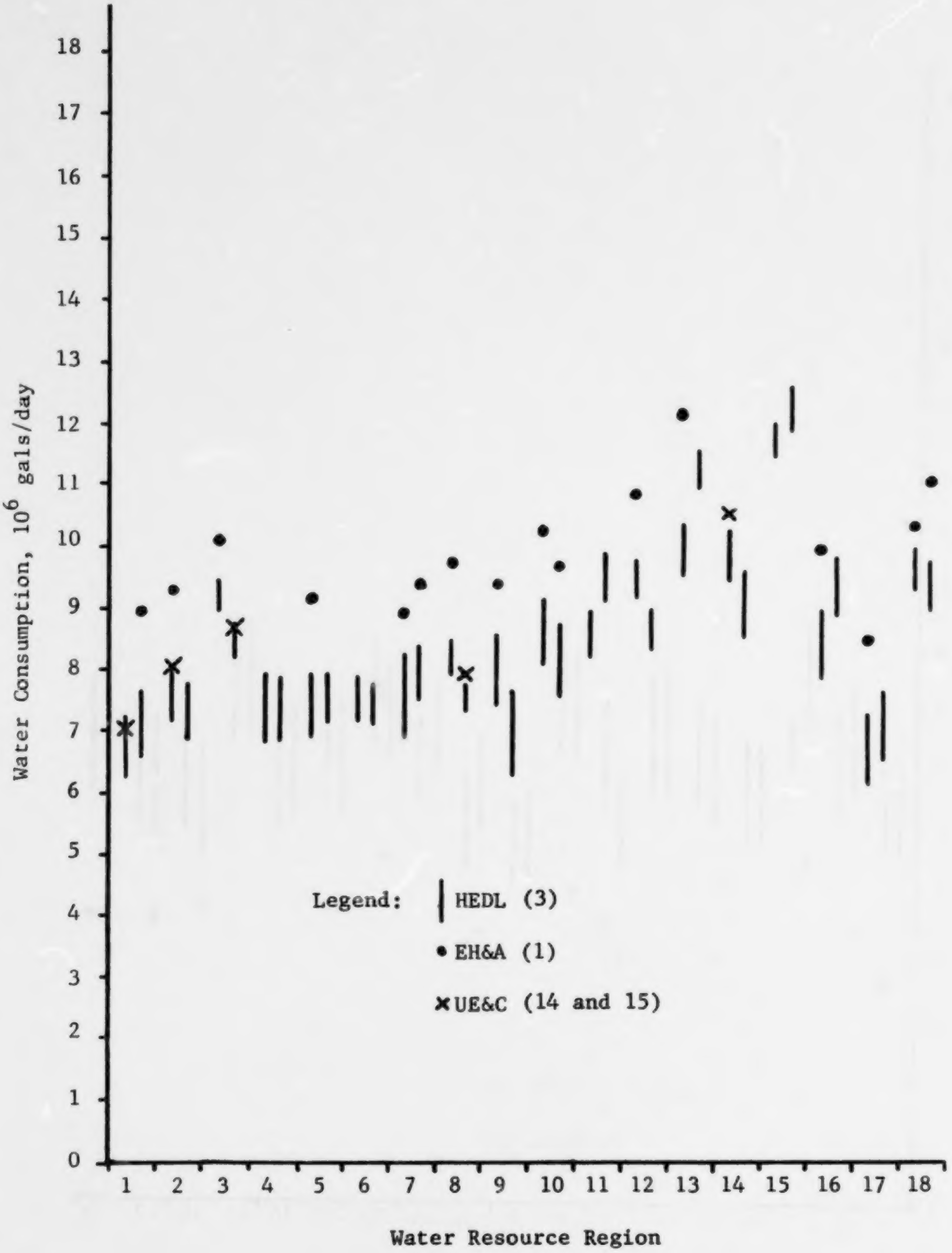

Figure 5.4 Cooling Towers With Makeup Pond (Blowdown Returned)

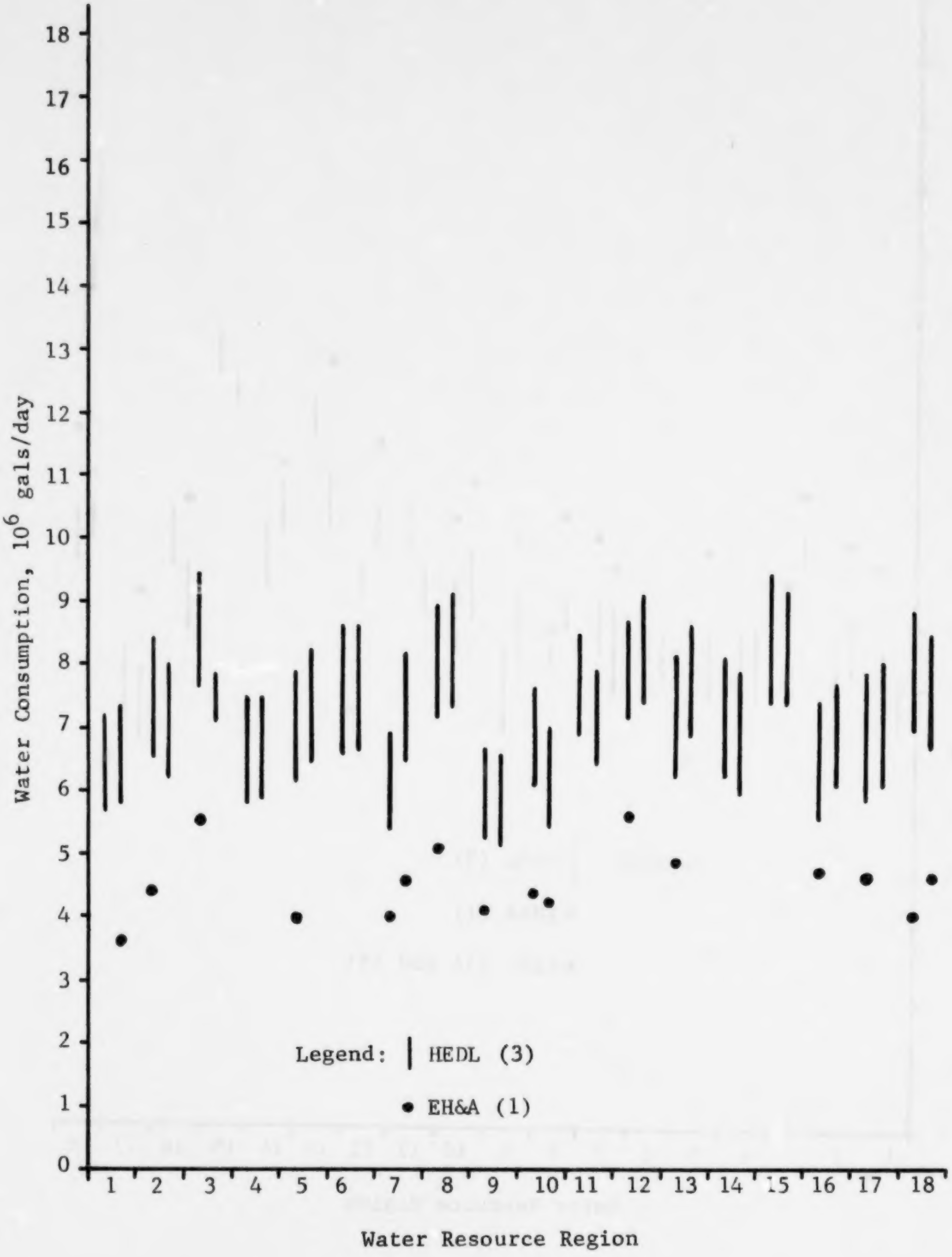

Figure 5.5 Multipurpose Cooling Ponds

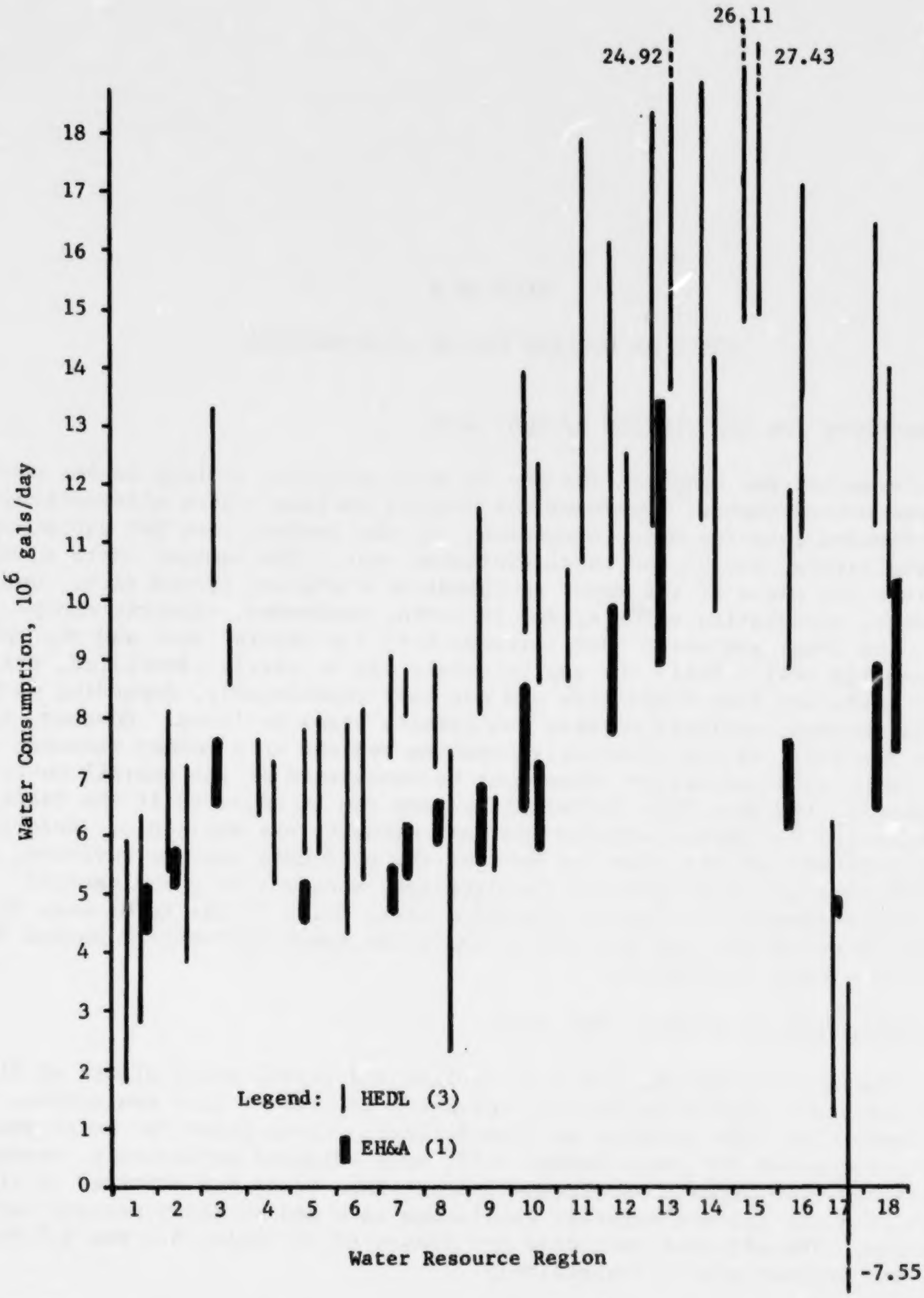

Figure 5.6 Single Purpose Cooling Ponds

SECTION 6

COSTS OF COOLING SYSTEM ALTERNATIVES

6.1 PROCEDURE FOR COMPILATION OF COST DATA

Cost information was compiled for the 18 water resource regions in the conterminous United States. Costs of the various cooling system alternatives can be divided into two main categories: 1) the capital cost for equipment and installation, and 2) the total evaluated cost. The capital costs normally include the costs of the major equipment of a cooling system (i.e., cooling device, circulating water system including condenser, electric equipment). The total evaluated cost includes both the capital cost and the operating penalty cost. While the capital costs can be easily identified, the penalty costs are less definitive and can vary considerably, depending on the economic factors, analysis methods and penalty items included. However, to compare the costs of the alternative cooling systems on a common economic basis, these less definitive items must be considered in the overall cost. In principle, the data from different sources can be adjusted if the basic information or design performance and cost elements are available. Unfortunately, this was not the case for most of the cost data sources reviewed. Therefore, for the data from all the different sources, only the capital costs are presented. The total evaluated cost, which is the total cost for cooling, is extracted from references where the basic information needed for proper adjustment is available.

6.2 COMPILATION OF CAPITAL COST DATA

Capital costs were compiled for both nuclear and fossil power plants of different sizes and year of commercial operation or year of cost evaluation. These costs were then adjusted to 1978 dollars. Costs given for prior years, or costs estimated for years beyond 1978, were adjusted accordingly, assuming a composite seven percent escalation index. This index was obtained as the average of a six percent material escalation rate and an eight percent labor escalation. The adjusted cost data are presented in Tables 6.1 and 6.2 for fossil and nuclear plants respectively.

The costs of conventional cooling systems have been grouped into four categories in the above tables. These are: 1) once-through cooling, 2) wet (evaporative) cooling towers, 3) cooling ponds, and 4) dry cooling towers. Within each category there are various design variations and operational schemes. These include fresh and saltwater operations for all the cooling systems mentioned above except the dry cooling systems, mechanical and natural draft designs for towers, man-made ponds and natural cooling lakes for ponds, and operations with conventional and high back pressure turbines for dry towers. Also included in these tables are two wet/dry tower systems designed to conserve water, i.e., to reduce the water consumption of comparable wet tower systems. The wet/dry systems will be discussed in Section 6.3.

The capital cost data presented in Tables 6.1 and 6.2 indicated a wide range for each cooling system category. In addition, the ranges of cost overlap for the different cooling system categories. Therefore, it is difficult to compare the costs of alternative cooling systems solely on the basis of capital cost because of the differences in basic assumptions, cost elements included, locations, etc.

Although it is not borne out by the capital data presented in these two tables, the following observations were made. The systems designed for saltwater operation are generally more costly than those designed for fresh water operation because of corrosion, size and operational considerations as illustrated in Table 6.3(21). The mechanical draft towers and the natural draft towers do not differ substantially in cost, although the natural draft towers are usually slightly higher in capital cost(3). The costs of cooling ponds can differ widely depending on whether the pond is man-made or natural and whether the site conditions and land costs are conducive to the construction of a pond. The dry systems which use high back pressure turbines usually have much lower capital costs than those which use low pressure conventional turbines(2,16).

6.3 COMPILATION OF TOTAL COST DATA FOR COOLING SYSTEMS

The total cost of a cooling system includes both the capital and penalty costs and is called the total evaluated cost. The total evaluated costs presented in Tables 6.4 and 6.5 for fossil and nuclear plants are adjusted from the data given in references indicated in the tables, using the same fixed source/fixed demand method as given in these references. The method assumes that any reduction of plant capability below its firm power rating must be replaced by additional generating capacity, such as the capacity from fossil or nuclear base load units which are similar to the power plant under consideration. The economic factors used for the adjustment of costs are given in Table 6.6. All the data are for fresh water operation, with the exception of the data derived from Reference 1, which were designed for saltwater application.

The adjustment of the capital cost component has already been discussed in Section 6.2. The penalty cost includes five components. These are the charges for the loss of generating capability relative to the firm rating of the plant at the peak ambient temperature, the energy loss due to ambient effect on cooling systems during a given year, the capability and energy required to run the cooling system pumps and fans, and the charge for cooling system maintenance.

The penalty charge for capability replacement represents the capital cost of generating equipment elsewhere in the utility system which is used to make up the capability losses of the plant. The energy costs are the costs needed to provide energy to operate the makeup capacity during an annual cycle. The maintenance cost is the cost charged to a cooling system for periodic maintenance and replacement of parts. Both the energy costs and the maintenance costs are generally capitalized to represent the costs which will accrue over the lifetime of the plant.

In adjusting the cost data, the costs of water to makeup the water consumption of cooling systems have been subtracted from the original data. The cost of water includes the cost for the purchase of water, the capital and operating cost of chemical treatment, pumping cost, and blowdown disposal cost. Water cost is practically nil for dry cooling systems and is usually small for plants using wet cooling systems with fresh water and located near a water body. This penalty cost is of special significance when making cost comparisons of the wet tower systems and the wet/dry tower systems designed for water conservation. This will be discussed in more detail in the next section.

The data presented in Tables 6.4 and 6.5 indicate that the total cost of cooling, i.e., the total evaluated cost, ranges from approximately 0.5 to 4 mills/kWh for fossil plants and 1 to 6 mills/kWh for nuclear plants in 1978 dollars. Once-through cooling has the lowest cost, and dry cooling has the highest cost. The data also indicate that the total evaluated costs of all conventional systems, exclusive of the constructed pond and the dry cooling systems, do not differ substantially from each other. The cost data for the constructed pond given in (3) did not include the effect of site topography on the pond construction; consequently the capital cost may not be representative of the actual cost of constructed ponds. As expected, the costs of wet/dry tower systems fall between the wet and dry tower systems.

6.4 IMPACT OF DEVELOPING TECHNOLOGY ON WATER CONSUMPTION AND COST

The technology being developed and applied to reduce water consumption in commercial power plants is wet/dry cooling. Specifically, it uses a combination of wet and dry cooling towers to reduce the water consumption of wet cooling towers. The water consumption referred to here is defined as the sum of the water evaporated and the blowdown from the tower. It corresponds to the case of tower with blowdown retained as discussed in Section 5.

Although there is no operating experience for the wet/dry system at this time, two wet/dry cooling systems designed to reduce the water consumption of comparable wet tower systems by 60 percent have been purchased by the Public Service Company of New Mexico for its San Juan Units Nos. 3 and 4. These 450 MWe fossil plants are scheduled to be operational in 1979 and 1981, respectively. The wet/dry system with a 60 percent reduction in water consumption is called a 40 percent system, meaning it consumes 40 percent of water needed for a comparably-rated (heat transfer) wet tower system.

The current design of wet/dry towers for water conservation is composed of separate wet and dry towers joined by a circulating water circuit. The component wet and dry towers can be both structurally and functionally separated (similar to those investigated in References 2 and 16) or structurally integrated but functionally separated (similar to those designed for the San Juan units(15)). All of these wet/dry towers are designed for use with conventional low back pressure turbines.

In these wet/dry systems, the dry tower is the main heat rejection device, and the wet tower is primarily used for augmenting the dry cooling capability at higher ambient conditions. These cooling systems can be designed to reduce water consumption of a comparable wet tower system by any desired amount, typically 60 to 99 percent, resulting in 40 percent to 1 percent systems. The accompanying increases in cost compared to wet tower systems are, however, substantial, being higher for the higher reduction in water consumption. This is shown in Tables 6.4 and 6.5 which contain data derived from two major studies(2,16) and a subsequent study(1) on wet/dry tower systems designed for water conservation. Reference 2 provided the data for nuclear plants and Reference 16 provided the data for fossil plants; Reference 1 was for a specific power plant. The detailed data, given in References 1, 2, and 16 and those presented in Tables 6.4 and 6.5 indicates that:

1. There is a step increase in the total evaluated cost from the wet to the 40 percent wet/dry tower system evaluated.
2. The costs increase approximately linearly between the 40 percent and the 10 percent wet/dry systems.
3. There is a sharp cost increase for wet/dry systems below approximately 10 percent make-up requirements.
4. There is step increase in cost from the wet/dry system as low as 1 percent makeup requirement to the dry cooling system which do not require make-up water.
5. The cost of water has a significant impact on the relative cost comparison of wet and wet/dry cooling systems.

Items 1, 3 and 4 are also evident from the data presented in Tables 6.4 and 6.5.

As indicated in Section 6.3, the data in the above mentioned two tables have excluded the cost of water which depends not only on the quantity of the makeup required but also on the water quality and water supply conditions of a specific power plant. The data for the proposed Sundesert Nuclear Project (1) and the Kaiparowits fossil station(16) illustrate the effect of water cost on the comparison of wet/dry and wet tower systems. The data adjusted according to the economic factors in Table 6.6 are given in Tables 6.7 and 6.8. As indicated earlier, the water cost for each wet or wet/dry system includes the cost for the purchase of water, the capital and operating cost, chemical treatment, pumping cost and blowdown disposal cost. These data indicate that, with the inclusion of the cost of water, the impact of the use of wet/dry cooling to conserve water may be significantly reduced but remains substantial.

6.5 CONCLUSIONS

The following are the conclusions derived from the results compiled and presented in this section:

1. It is difficult to compare the cost of alternative cooling systems solely on the basis of capital cost. The ranges of

cost overlap for different cooling system alternatives.

2. There is no discernable trend of the capital cost of cooling system by regions.
3. As expected, the total evaluated cost of once-through cooling is the lowest and that of dry cooling is the highest; other closed-cycle conventional systems lie between these extremes. The total evaluated costs of wet tower systems and spray pond systems do not differ substantially.
4. The cost impact of the use of dry cooling to conserve water may be significantly reduced with the use of wet/dry cooling; however, the absolute cost of wet/dry cooling is significantly greater than that of wet cooling.

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TABLE 6.1

CAPITAL COSTS OF COOLING SYSTEM ALTERNATIVES - FOSSIL PLANTS ($/KW, 1978 DOLLARS)

Water Resource Region	Once Through	Wet Tower	Cooling Pond	40% Wet/Dry*	10% Wet/Dry*	Dry Tower: High Back Pressure Turbine	Dry Tower: Low Back Pressure Turbine
1. New England	$15^{(3)}$	$22\text{-}28^{(3)}$	$39^{(3)}$			$34\text{-}38^{(3)}$	
2. Middle Atlantic		$26\text{-}27^{(16)}$		$43^{(16)}$	$56^{(16)}$	$45^{(16)}$	$85^{(16)}$
3. S. Atlantic-Gulf	$19^{(20)}$	$24\text{-}26^{(16)}$, $28^{(3)}$, $22\text{-}37^{(20)}$	$63^{(20)}$	$53^{(20)}$			
4. Great Lakes		$25^{(7)}$, $21\text{-}23^{(8)}$, $44\text{-}57^{(5)}$	$22^{(8)}$, $44^{(5)}$	$27^{(8)}$		$62^{(7)}$	
5. Ohio		$25^{(16)}$, $19\text{-}25^{(6)}$				$39\text{-}45^{(5)}$	
6. Tennessee							
7. Upper Mississippi		$19^{(10)}$				$30^{(10)}$	
8. Lower Mississippi							
9. Souris-Red-Rainy							
10. Missouri Basin		$23^{(16)}$		$38\text{-}43^{(16)}$	$47\text{-}52^{(16)}$	$47^{(16)}$	$101\text{-}103^{(16)}$
11. Arkansas-White-Red							
12. Texas-Gulf	$36^{(26)}$		$62^{(26)}$				
13. Rio Grande							
14. Upper Colorado		$21\text{-}26^{(3)}$, $22\text{-}24^{(16)}$		$39\text{-}44^{(16)}$	$49\text{-}57^{(16)}$	$46\text{-}49^{(16)}$	$88\text{-}108^{(16)}$
15. Lower Colorado				$52\text{-}67^{(15)}$		$73\text{-}87^{(15)}$	
16. Great Basin							
17. Pacific Northwest		$25^{(16)}$, $25\text{-}27^{(35)}$	$69^{(35)}$			$59^{(35)}$	
18. California							

References given in superscripted parentheses.

* 40% (10%) wet/dry has 40% (10%) of the water consumption of a wet system designed to reject the same quantity of heat.

TABLE 6.2

CAPITAL COSTS OF COOLING SYSTEM ALTERNATIVES - NUCLEAR PLANTS ($/KW, 1978 DOLLARS)

						Dry Tower	
Water Resource Region	Once Through	Wet Tower	Cooling Pond	40% Wet/Dry*	10% Wet/Dry*	High Back Pressure Turbine	Low Back Pressure Turbine
1. New England	38(25), 21(3), 24(9)	28-30(3), 28-32(9), 31(2)	51(3), 41(25) 24-28(9)	55(2)	58(2)	47-57(3), 62(2)	123(2)
2. Middle Atlantic	58(29)	44-48(27), 54-61(29), 46-53(33)		60(19)		37-39(14)	
3. S. Atlantic-Gulf		32(2), 31-32(3)		61(2), 46(19)	75(2)	66(2)	125(2)
4. Great Lakes		24-29(32)				79(27)	
5. Ohio			27-28(5), 14-20(5)			43-69(5)	
6. Tennessee		23-27(28), 32-34(31)					
7. Upper Mississippi							
8. Lower Mississippi							
9. Souris-Red-Rainy							
10. Missouri Basin	27(34)	37-40(34), 21(7)				65(7)	
11. Arkansas-White-Red		33-36(30)					
12. Texas-Gulf	13-14(18)	26(7), 20(18)	26-28(18)			75(7), 29-38(18)	
13. Rio Grande							
14. Upper Colorado		30(2), 27-30(3)		59(2)	78(2)	68(2)	150(2)
15. Lower Colorado		21(7)				67(7)	
16. Great Basin							
17. Pacific Northwest							
18. California		45(1), 33(11)	79(5)	71(1), 95(11)	102(1), 125(11)		

References given in superscripted parentheses.

* 40% (10%) wet/dry has 40% (10%) of the water consumption of a wet system designed to reject the same quantity of heat.

TABLE 6.3 PERCENTAGE INCREASES IN CAPITAL COSTS FOR SALTWATER COOLING SYSTEMS (50,000 ppm) RELATIVE TO FRESHWATER COOLING SYSTEMS (21)

	Typical Division of Total Capital Expenses by Component, percent	Percent Increase		
		Without Materials	Materials Only	Total
RESEARCH-COTTRELL				
Natural-Draft Cooling Systems				
Cooling Tower	72	4.2 - 4.4	0	4.2 - 4.4
Condenser	20	1.5 - 3.6	15.5 - 15.9	17.0 - 19.5
Other	8	5.3 - 8.5	0	5.3 - 8.5
Total Capital	100	3.7 - 4.6	3.0 - 3.2	6.7 - 7.8
WESTINGHOUSE POWER GENERATION SYSTEMS				
Natural-Draft Cooling Systems				
Cooling Tower	53	5.0	0	5.0
Condenser	27	3.7	6.8	10.5
Other	20	3.7	0	3.7
Total Capital	100	4.6	1.7	6.3
Mechanical-Draft Cooling Systems				
Cooling Tower	37	5.5	0	5.5
Condenser	34	4.1	7.0	11.1
Other	29	0.6	0	0.6
Total Capital	100	3.6	2.3	5.9
ECODYNE				
Natural-Draft Cooling Tower		1.8 - 2.9		
Mechanical-Draft Cooling Tower		2.2 - 3.6		

TABLE 6.4

SUMMARY OF COSTS FOR COOLING SYSTEMS FOR FOSSIL PLANTS

Cooling System	Water Resources Region		Location	Capital Cost		Penalty Cost		Total Evaluated Cost		Ref.
				$/KW	Mills/ KWHR	$/KW	Mills/ KWHR	$/KW	Mills/ KWHR	
Once Through	1	New England	Boston, Mass.	15.16	0.42	4.55	0.12	19.71	0.54	3
Mechanical Wet	1	New England	Boston, Mass.	21.57	0.59	21.50	0.59	43.07	1.18	3
	2	Middle Atlantic	Newark, N.J.	26.20	0.72	17.97	0.49	44.17	1.21	16
			New Hampton, N.Y.	27.13	0.74	16.67	0.46	43.80	1.20	16
	3	South Atlantic-Gulf	Charlotte, N.C.	26.20	0.72	16.87	0.46	43.07	1.18	16
			Miami, Florida	24.19	0.66	23.99	0.66	48.18	1.32	3
	5	Ohio	Cleveland, Ohio	25.21	0.69	16.40	0.45	41.61	1.14	16
	10	Missouri Basin	Colstrip, Montana	23.40	0.64	18.21	0.50	41.61	1.14	16
			Young, North Dakota	22.87	0.63	19.11	0.52	41.98	1.15	16
	14	Upper Colorado	Denver, Colorado	21.16	0.58	17.17	0.47	38.33	1.05	3
			Kaiparowits, Utah	23.60	0.65	19.25	0.52	42.85	1.17	16
			Rock Springs, Wyoming	22.42	0.61	15.91	0.44	38.33	1.05	16
			San Juan, New Mexico	22.88	0.63	17.64	0.48	40.52	1.11	16
	17	Pacific Northwest	Seattle, Washington	25.25	0.69	14.90	0.41	40.15	1.10	16
Natural Wet	1	New England	Boston, Mass.	26.96	0.74	20.13	0.55	47.09	1.29	3
	3	South Atlantic-Gulf	Miami, Florida	27.57	0.76	23.53	0.64	51.10	1.40	3
	14	Upper Colorado	Denver, Colorado	25.11	0.69	16.50	0.45	41.61	1.14	3
Fan Assisted	1	New England	Boston, Mass.	27.77	0.76	17.86	0.49	45.63	1.25	3
	3	South Atlantic-Gulf	Miami, Florida	28.15	0.77	23.32	0.64	51.47	1.41	3
	14	Upper Colorado	Denver, Colorado	26.47	0.73	15.14	0.41	41.61	1.14	3
Cooling Pond	1	New England	Boston, Mass.	38.50	1.05	23.55	0.65	62.05	1.70	3
Spray Canal	1	New England	Boston, Mass.	23.99	0.66	20.18	0.55	44.17	1.21	3
40% Wet/Dry	2	Middle Atlantic	New Hampton, N.Y.	43.23	1.18	37.80	1.04	81.03	2.22	16
	10	Missouri Basin	Colstrip, Montana	42.64	1.17	36.20	0.99	78.84	2.16	16
			Young, North Dakota	37.66	1.03	44.47	1.22	82.13	2.25	16
	14	Upper Colorado	Kaiparowits, Utah	39.48	1.08	45.22	1.24	84.70	2.32	16
			Rock Springs, Wyoming	39.15	1.07	34.95	0.96	74.10	2.03	16
			San Juan, New Mexico	43.60	1.19	37.07	1.02	80.67	2.21	16

TABLE 6.4 (cont'd)

Cooling System	Water Resources Region	Location	Capital Cost $/KW	Capital Cost Mills/KWHR	Penalty Cost $/KW	Penalty Cost Mills/KWHR	Total Evaluated Cost $/KW	Total Evaluated Cost Mills/KWHR	Ref.
10% Wet/Dry	2 Middle Atlantic	New Hampton, N.Y.	56.07	1.54	41.02	1.12	97.09	2.66	16
	10 Missouri Basin	Colstrip, Montana	51.95	1.42	45.87	1.26	97.82	2.68	16
	14 Upper Colorado	Young, North Dakota	47.21	1.29	50.25	1.38	97.46	2.67	16
		Kaiparowits, Utah	49.28	1.35	45.00	1.23	94.28	2.58	16
		Rock Springs, Wyoming	52.34	1.43	38.91	1.07	91.25	2.50	16
		San Juan, New Mexico	56.89	1.56	47.50	1.30	104.39	2.86	16
Mechanical Dry With High Pressure Turbine	1 New England	Boston, Mass.	34.29	0.94	98.94	2.71	133.23	3.65	3
	2 Middle Atlantic	New Hampton, N.Y.	45.16	1.24	96.10	2.63	141.26	3.87	16
	10 Missouri Basin	Colstrip, Montana	47.43	1.30	99.30	2.72	146.73	4.02	16
	14 Upper Colorado	Young, North Dakota	47.28	1.30	101.64	2.78	148.92	4.08	16
		Kaiparowits, Utah	49.43	1.35	96.21	2.64	145.64	3.99	16
		Rock Springs, Wyoming	45.74	1.25	95.15	2.61	140.89	3.86	16
		San Juan, New Mexico	47.61	1.30	100.95	2.77	148.56	4.07	16
Mechanical Dry With Low Pressure Turbine	2 Middle Atlantic	New Hampton, N.Y.	84.60	2.32	53.01	1.45	137.61	3.77	16
	10 Missouri Basin	Colstrip, Montana	101.07	2.77	57.71	1.58	158.78	4.35	16
	14 Upper Colorado	Young, North Dakota	102.59	2.81	58.01	1.59	160.60	4.40	16
		Kaiparowits, Utah	107.83	2.95	54.23	1.49	162.06	4.44	16
		Rock Springs, Wyoming	87.51	2.40	53.02	1.45	140.53	3.85	16
		San Juan, New Mexico	101.14	2.77	59.83	1.64	160.97	4.41	16
Natural Dry With High Pressure Turbine	1 New England	Boston, Mass.	37.87	1.04	89.52	2.45	127.39	3.49	3

TABLE 6.5

SUMMARY OF COSTS FOR COOLING SYSTEMS FOR LWR PLANTS

Cooling System	Water Resources Region		Location	Capital Cost		Penalty Cost		Total Evaluated Cost		Ref.
				$/KW	Mills/ KWHR	$/KW	Mills/ KWHR	$/KW	Mills/ KWHR	
Once Through	1	New England	Boston, Mass.	21.03	0.58	5.25	0.14	26.28	0.72	3
Mechanical Wet	1	New England	Boston, Mass.	27.53	0.75	21.75	0.60	49.28	1.35	3
			Boston, Mass.	30.99	0.85	21.21	0.58	52.20	1.43	2
	3	South Atlantic-Gulf	Atlanta, Ga.	32.05	0.88	21.61	0.59	53.66	1.47	2
			Miami, Florida	30.55	0.84	22.74	0.62	53.29	1.46	3
	14	Upper Colorado	Denver, Colorado	26.99	0.74	17.91	0.49	44.90	1.23	3
			San Juan, New Mexico	30.39	0.83	17.43	0.48	47.82	1.31	2
	18	California	Blythe, California	44.70	1.22	22.46	0.62	67.16	1.84	1
Natural Wet	1	New England	Boston, Mass.	29.83	0.82	20.54	0.56	50.37	1.38	3
	3	South Atlantic-Gulf	Miami, Florida	31.38	0.86	21.55	0.59	52.93	1.45	3
	14	Upper Colorado	Denver, Colorado	28.65	0.78	17.34	0.48	45.99	1.26	3
Fan Assisted Natural Draft	1	New England	Boston, Mass.	32.36	0.89	19.11	0.52	51.47	1.41	3
	3	South Atlantic-Gulf	Miami, Florida	31.91	0.87	22.48	0.62	54.39	1.49	3
	14	Upper Colorado	Denver, Colorado	30.38	0.83	16.71	0.46	47.09	1.29	3
Cooling Pond	1	New England	Boston, Mass.	50.72	1.39	21.92	0.60	72.64	1.99	3
Spray Pond	1	New England	Boston, Mass.	25.45	0.70	25.65	0.70	51.10	1.40	3
40% Wet/Dry	1	New England	Boston, Mass.	54.90	1.50	38.54	1.06	93.44	2.56	2
	3	South Atlantic-Gulf	Atlanta, Ga.	61.22	1.68	40.25	1.10	101.47	2.78	2
	14	Upper Colorado	San Juan, New Mexico	58.94	1.61	38.52	1.06	97.46	2.67	2
	18	California	Blythe, California	71.32	1.95	58.26	1.60	129.58	3.55	1
10% Wet/Dry	1	New England	Boston, Mass.	67.72	1.86	43.61	1.19	111.33	3.05	2
	3	South Atlantic-Gulf	Atlanta, Ga.	75.25	2.06	52.87	1.45	128.12	3.51	2
	14	Upper Colorado	San Juan, New Mexico	77.66	2.13	51.55	1.41	129.21	3.54	2
	18	California	Blythe, California	102.41	2.81	70.24	1.92	172.65	4.73	1

TABLE 6.5 (cont'd)

Cooling System	Water Resources Region		Location	Capital Cost		Penalty Cost		Total Evaluated Cost		Ref.
				$/KW	Mills/ KWHR	$/KW	Mills/ KWHR	$/KW	Mills/ KWHR	
Mechanical Dry With High Pressure Turbine	1	New England	Boston, Mass.	61.94	1.70	107.42	2.94	169.36	4.64	2
			Boston, Mass.	46.89	1.28	122.84	3.37	169.73	4.65	3
	3	South Atlantic-Gulf	Atlanta, Ga.	65.83	1.80	106.09	2.91	171.92	4.71	2
	14	Upper Colorado	San Juan, New Mexico	67.92	1.86	112.39	3.08	180.31	4.94	2
Mechanical Dry With Low Pressure Turbine	1	New England	Boston, Mass.	122.69	3.36	62.73	1.72	185.42	5.08	2
	3	South Atlantic-Gulf	Atlanta, Ga.	124.91	3.42	64.53	1.77	189.44	5.19	2
	14	Upper Colorado	San Juan, New Mexico	149.95	4.11	71.97	1.97	221.92	6.08	2
Natural Dry With High Pressure Turbine	1	New England	Boston, Mass.	57.34	1.57	104.36	2.86	161.70	4.43	3

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TABLE 6.6 - ECONOMIC FACTORS

	Nuclear	Fossil
Pricing Year	1978	1978
Average Plant Capacity Factor	0.75	0.75
Annual Fixed Charge Rate	18%	18%
Capacity Penalty Charge Rate ($/kW)	374	302
Fuel Cost ($/MBtu)	0.953	1.96
Operating and Maintenance Cost (Mills/kWhr)	0.451	1.58
Escalation Factor for Material/Equipment and Labor	7%	7%

TABLE 6.7

COMPARISON OF COSTS OF WET AND WET/DRY COOLING SYSTEMS FOR A FOSSIL PLANT ($/KW)

SITE: KAIPAROWITS, UTAH YEAR: 1978

Cooling Tower	WET/DRY			WET
Annual Make-up Water Quantity	2%	10%	40%	100%
Total Capital Cost of The Base Cooling System*	60.59	49.28	39.48	23.60
Total Penalty Cost of The Base Cooling System*	44.95	45.00	45.22	19.25
Total Evaluated Cost of The Base Cooling System*	105.54	94.28	84.70	42.85
Total Water Penalty Cost	13.17	16.52	21.24	28.12
Total Evaluated Cost of The Complete Cooling System	118.71	110.80	105.94	70.97

* Base Cooling System - Cooling System Without Make-up and Blowdown Facilities.

TABLE 6.8

COMPARISON OF COSTS OF WET AND WET/DRY COOLING SYSTEMS FOR A NUCLEAR PLANT ($/KW)

SITE: BLYTHE, CALIFORNIA YEAR: 1978

Cooling Tower	WET/DRY			WET
Annual Make-up Water Quantity	5%	10%	40%	100%
Total Capital Cost of The Base Cooling System*	108.03	102.41	71.44	44.71
Total Penalty Cost of The Base Cooling System*	76.54	70.27	58.18	22.32
Total Evaluated Cost of The Base Cooling System*	184.57	172.68	129.62	67.03
Total Water Penalty Cost	11.88	14.97	30.44	54.14
Total Evaluated Cost of The Complete Cooling System	196.45	187.65	160.06	121.17

* Base Cooling System - Cooling System Without Make-up and Blowdown Facilities.

SECTION 7

ESTIMATED AVAILABILITY OF WATER FOR ALL USES IN THE CONTERMINOUS UNITED STATES

7.1 INTRODUCTION

The purpose of this section is to present data on the estimated water availability in the conterminous United States for all uses in general, and for steam electric power plant cooling in particular. At the present time, the availability of environmentally acceptable sites for electric power generating plants, whether fossil or nuclear, is strongly influenced by the availability of cooling water. Water can no longer be considered an infinite, undepletable resource. Today, chronic water shortages exist in parts of ths conterminous United States. Water supply in these areas at certain times does not satisfy even the basic human needs, let alone provide for expansion of industry, agriculture, or electric power generating facilities. Even in areas where water is apparently available in a physical sense, the right to its use may be constrained by laws and regulations. These include laws that deal with Federal and Indian water rights, state water laws, minimum flow regulations, interstate compacts, international treaties, prior appropriation and the like. An overview of these laws and regulations is given in Section 8 of this document.

Water quantity and quality are becoming dominant characteristics influencing industrial, agricultural or domestic expansion in a particular geographic region. In the arid or semi-arid areas, excessive consumption of existing natural water flows will increase salinity of these steams and potentially impact navigation on major arteries.

Steam electric power plants are affected more severely than other components of the national economy, because this component of the economy is expected to expand at a greater rate than the other highly water-dependent sectors of the economy. As late as the 1960's, power plants used once-through cooling systems almost exclusively to cool and condense the steam that drives conventional electrical generating machinery. However, projections of electrical capacity requirements have indicated that sufficient cooling water for once-through cooling is only available on the major rivers, lakes and coastal regions of the United States.

Currently, many of the new major generating plants and those expected to be constructed during the remainder of this century will probably have to use closed-cycle cooling in order to reduce potential adverse thermal impacts below allowable limits set by law. However, the more efficient and economical cooling systems require evaporation of a small fraction of the water used for condenser cooling. Thus, a quantity of water is consumed and "lost" to the atmosphere. The impact of allocating the available geographical water resources is a critical environmental factor for all potential water uses, including power plant construction.

7.2 METHODOLOGY FOR ESTIMATING WATER AVAILABILITY

The water availability data presented in this report are based on the results of a comprehensive study (1) performed by the U.S. Water Resources Council (WRC). The Water Resources Council was established by the Water Resources Planning Act of 1965 to maintain, among other responsibilities, a continuing study of the adequacy of water supply in the United States. A four-year effort by the Council to identify and describe the Nation's water resources and areas with severe water problems was recently completed and a final report of the study is expected to be issued by the Council early in 1978.

This study has been accomplished by the cooperative activities of state, regional, and federal agencies under the overall direction of the Water Resources Council.

In the WRC study, the conterminous United States is divided into 18 water resource regions which are further subdivided into 217 subregions. These subregions, in turn, are combined to form 99 aggregated subregions or ASR's, loosely determined by existing major river basins. Table 7.1 lists the 18 water resource regions and 99 aggregated subregions, and Figure 7.1 shows them graphically.

Figure 7.1 also shows the routing of outflows for the conterminous United States. These routings are summarized on Table 7.2 for each ASR and the interconnected ASR's. Figure 7.1 is a schematic and does not show the exact location of the outflow points.

Basic input data for each of the 99 ASR's and 18 water resource regions have been systematically organized and analyzed by WRC. The end result of this assessment includes tabulated data on many areas of interest to this section of the present study. A list of the tables compiled in the Statistical Appendix (1) to the WRC's Assessment is shown in Table 7.3.

The water availability analysis was performed for the 18 water resource regions and the most water-deficient ASR within each of the 18 regions. The water availability data were tabulated for the years 1975, 1985, and 2000. The latter two years were assumed to have dry year flow conditions.

Dry year water use data were based on requirements for a dry year occurring fewer than 20 times in each 100 years but having withdrawals limited by an 80 percent exceedance monthly water supply. In the WRC's Assessment, only the irrigation and steam electric uses were estimated differently for the dry and average year. Percentage exceedance refers to a statistical estimate of the probability of flow. For example, a 5 percent exceedance annual stream flow will be exceeded in about 5 years of each 100-year period.

From the data given in the WRC's assessment (1), water availability results were calculated and presented in Tables 7.4 and 7.5. Each table lists the specific data from Reference (1) which were used in preparing Tables 7.4 and 7.5. Also listed are the explanatory notes taken from Reference 1 which provide assistance in the interpretation of specific WRC data used in the present analysis.

Table 7.4 organizes consumptive water users into four major categories as follows:

1. Public Supply, including:
    a. Domestic
    b. Commercial
    c. Public land
    d. Fish hatcheries
2. Agriculture
3. Industry and Mining, including:
    a. Manufacturing
    b. Minerals
4. Steam Electric

Table 7.4 also gives the total water consumption as well as the percentage of water required for steam electric generation cooling systems as a part of the total water consumption.

Table 7.5 tabulates data on the following quantities:

Column Number	Variable
1.	Total stream flow
2.	Total water consumption (same as in Table 7.4)
3.	Total stream flow depletion due to the actual consumptive use + net evaporation + exports - imports
4.	Minimum flow desired from the fish and wildlife standpoint
5.	Water available for consumption after subtracting the minimum flow for fish and wildlife from the total stream flow
6.	Total depletion of the stream flow (percentage)
7.	Depletion of the stream flow due to steam electric generator consumption (percentage)

The analytical expressions used for calculating these quantities are defined in the footnotes to Table 7.5. The input data used were taken from Tables 17, 19 and 33A of the WRC's Assessment.

7.3 DISCUSSION

Based upon the results compiled and correlated in this section, the following observations can be made:

1. With respect to the results presented in Table 7.4:

    a. The average percentages of steam electric generation consumptive water use relative to the total consumption in the years 1975, 1985, and 2000 in the conterminous United States are 1.23%, 3.10%, and 7.22%, respectively. By contrast, the corresponding numbers for the largest water consumer, agriculture, are 84.60%, 81.04%, and 73.20%. Taking 1975 as a reference year, the water consumption for steam electric generation is estimated to increase by 9158 MGD by the year 2000, whereas the water consumption in agriculture is estimated to increase by 8318 MGD.

    b. Percentagewise, the largest water consumption for steam electric generation is projected to occur in the following water resouces regions: Ohio, Tennessee, Upper Mississippi, Great Lakes, Mid-Atlantic, and New England.

2. With respect to the results presented in Table 7.5:

    a. The total stream flow for a region was calculated based only on surface water resources; that is, ground water was not considered to be available for future consumption.

    b. The total water depletion for a given region is generally slightly larger than the consumption by the users of that region because of the net natural evaporation. The latter was calculated only for lakes and reservoirs having storage volumes in excess of 5000 acre-feet. For some water resource regions where the water additions (imports) exceed the water reductions (exports), the stream flow is depleted by an amount smaller than the combined total of the water consumption and natural evaporation. The opposite is true for regions where the water exports exceed the water imports.

    c. The minimum flow desired from the fish and wildlife standpoint was tabulated only to enable the calculation of the amount of water available for consumptive use if this criterion is observed. Since the minimum flow exceeds the total stream flow available for the dry year conditions, the excess water available for consumption becomes negative is most regions, that is, the consumptive water available is less than the demand.

d. The general trend predicted for the consumptive use shows that the stream flow depletion will worsen in the future.

3. The information correlated from the WRC's assessment data and presented in the section does not specifically relate the water availability for the different hydrologic units to the consumptive water requirements of various cooling systems and to the potential impact of using one form of cooling system relative to another. To make such a correlation would require a computerized information retrieval system to process a massive amount of data on water availibility, water consumption for various cooling alternatives, cooling systems mix, and power capacity in all of the hydrologic units of the United States. Such a task, however, is beyond the scope of work of the present study. In early April 1978, while revising the draft report of this study in preparation for publication, UE&C learned about the current development of such an Information Retrieval System (IRS) by the Hanford Engineering Development Laboratory. This information was reported in an article just published in the Proceedings of the American Power Conference (2). When complete, the IRS will apparently be capable of providing the necessary correlation as indicated above. The detailed capabilities of the IRS are given in Reference 2 and the current degree of completion is given in Reference 3.

7.4 CONCLUSIONS

From the analysis of the water availibility data compiled in Tables 7.4 and 7.5, the following conclusions can be drawn.

1. Under dry year conditions, there is not sufficient water in most regions of the conterminous United States to fully satisfy all users. This situation is particularly critical in the Southwest and will become worse in the future.

2. The percentage consumption for steam electric generation relative to the total consumption was 1.23% in 1975 and will grow to 3.10% in 1985 and to 7.22% in the year 2000.

3. Since agriculture consumes the largest quantity of water by comparison with other water users, substantial water savings can be accomplished even with small percentage reductions in agricultural use through better utilization of the water resources. Conversely, a large percentage reduction in the consumption for steam electric generation is small by comparison.

REFERENCES

1. United States Water Resources Council. The Nation's Water Resources, The Second National Assessment by the U.S. Water Resources Council. Statistical Appendix. Washington, 1978.

2. Peterson, D.E., and J.C. Sonnichsen, Jr. Assessment of Cooling Water Supply in the United States. Proceedings of the American Power Conference, 39:676-684,1977.

3. Hanford Engineering Development Laboratory. Water Use Information System (News Release). Richland, Washington, 1978.

TABLE 7.1 REGIONS AND AGGREGATED SUBREGIONS(1)

Region Number	ASR Number	Region / Aggregated Subregion
01		NEW ENGLAND
	0101	Northern Maine
	0102	Saco-Merrimack
	0103	Massachusetts-Rhode Island Coastal
	0104	Housatonic-Thames
	0105	Connecticut River
	0106	Richelieu
02		MID-ATLANTIC
	0201	Upper Hudson
	0202	Lower Hudson-Long Island-North New Jersey
	0203	Delaware
	0204	Susquehanna
	0205	Upper and Lower Chesapeake
	0206	Potomac
03		SOUTH ATLANTIC-GULF
	0301	Roanoke-Cape Fear
	0302	Pee Dee-Edisto
	0303	Savannah-St. Marys
	0304	St. Johns-Suwannee
	0305	Southern Florida
	0306	Apalachicola
	0307	Alabama-Choctawhatchee
	0308	Mobile-Tombigbee
	0309	Pascagoula-Pearl
04		GREAT LAKES
	0401	Lake Superior
	0402	Northwestern Lake Michigan
	0403	Southwestern Lake Michigan
	0404	Eastern Lake Michigan
	0405	Lake Huron
	0406	St. Clair-Western Lake Erie
	0407	Eastern Lake Erie
	0408	Lake Ontario
05		OHIO
	0501	Ohio Headwaters
	0502	Upper Ohio-Big Sandy
	0503	Muskingum-Scioto-Miami
	0504	Kanawha
	0505	Kentucky-Licking-Green-Ohio
	0506	Wabash
	0507	Cumberland
06		TENNESSEE
	0601	Upper Tennessee
	0602	Lower Tennessee

TABLE 7.1 (cont'd.)

Region Number	ASR Number	Region / Aggregated Subregion
07		UPPER MISSISSIPPI
	0701	Mississippi Headwaters
	0702	Black-Root-Chippewa-Wisconsin
	0703	Rock-Mississippi-Des Moines
	0704	Salt-Sny-Illinois
	0705	Lower Upper Mississippi
08		LOWER MISSISSIPPI
	0801	Hatchie-Mississippi-St. Francis
	0802	Yazoo-Mississippi-Ouachita
	0803	Mississippi Delta
09		SOURIS-RED-RAINY
	0901	Souris-Red-Rainy
10		MISSOURI
	1001	Missouri-Milk-Saskatchewan
	1002	Missouri-Marias
	1003	Missouri-Musselshell
	1004	Yellowstone
	1005	Western Dakotas
	1006	Eastern Dakotas
	1007	North and South Platte
	1008	Niobrara-Platte-Loup
	1009	Middle Missouri
	1010	Kansas
	1011	Lower Missouri
11		ARKANSAS-WHITE-RED
	1101	Upper White
	1102	Upper Arkansas
	1103	Arkansas-Cimarron
	1104	Lower Arkansas
	1105	Canadian
	1106	Red-Washita
	1107	Red-Sulphur
12		TEXAS-GULF
	1201	Sabine-Neches
	1202	Trinity-Galveston Bay
	1203	Brazos
	1204	Colorado (Texas)
	1205	Nueces-Texas Coastal
13		RIO GRANDE
	1301	Rio Grande Headwaters
	1302	Middle Rio Grande
	1303	Rio Grande-Pecos
	1304	Upper Pecos
	1305	Lower Rio Grande

TABLE 7.1 (cont'd.)

Region Number	ASR Number	Region / Aggregated Subregion
14		UPPER COLORADO
	1401	Green-White-Yampa
	1402	Colorado-Gunnison
	1403	Colorado-San Juan
15		LOWER COLORADO
	1501	Little Colorado
	1502	Lower Colorado Main Stem
	1503	Gila
16		GREAT BASIN
	1601	Bear-Great Salt Lake
	1602	Sevier Lake
	1603	Humboldt-Tonopah Desert
	1604	Central Lahontan
17		PACIFIC NORTHWEST
	1701	Clark Fork-Kootenai
	1702	Upper/Middle Columbia
	1703	Upper/Central Snake
	1704	Lower Snake
	1705	Coast-Lower Columbia
	1706	Puget Sound
	1707	Oregon Closed Basin
18		CALIFORNIA
	1801	Klamath-North Coastal
	1802	Sacramento-Lahontan
	1803	San Joaquin-Tulare
	1804	San Francisco Bay
	1805	Central California Coast
	1806	Southern California
	1807	Lahontan-South

TABLE 7.2 U.S. WATER RESOURCES COUNCIL
ROUTING OF SURFACE FLOWS FOR AGGREGATED SUBREGIONS(1)

REGIONS	AGGREGATED SUBREGIONS	AGGREGATED SUBREGIONS NETWORK
NEW ENGLAND REGION 01	101, 102, 103, 104, 105, 106	CLOSED BASINS: NONE 101 → ATLANTIC OCEAN 102 → ATLANTIC OCEAN 103 → ATLANTIC OCEAN 104 → ATLANTIC OCEAN 105 → ATLANTIC OCEAN 106 → CANADA
MID ATLANTIC REGION 02	201, 202, 203, 204, 205, 206	CLOSED BASINS: NONE 201 → 202 → ATLANTIC OCEAN 203 → ATLANTIC OCEAN 204 → CHESAPEAKE BAY/ ATLANTIC OCEAN 205 → CHESAPEAKE BAY/ ATLANTIC OCEAN 206 → CHESAPEAKE BAY/ ATLANTIC OCEAN
SOUTH ATLANTIC GULF REGION 03	301, 302, 303, 304, 305, 306, 307, 308, 309	CLOSED BASINS: NONE 301 → ATLANTIC OCEAN 302 → ATLANTIC OCEAN 303 → ATLANTIC OCEAN 304 → ATLANTIC OCEAN AND GULF OF MEXICO 305 → ATLANTIC OCEAN AND GULF OF MEXICO 306 → GULF OF MEXICO 307 → GULF OF MEXICO 308 → GULF OF MEXICO 309 → GULF OF MEXICO
GREAT LAKES REGION 04	401, 402, 403, 404, 405, 406 407, 408	CLOSED BASINS: NONE 401 → LAKE SUPERIOR 402 → LAKE MICHIGAN 403 → LAKE MICHIGAN 404 → LAKE MICHIGAN 405 → LAKE HURON 406 → LAKE ERIE 407 → LAKE ERIE 408 → LAKE ONTARIO

TABLE 7.2 (cont'd.)

REGIONS	AGGREGATED SUBREGIONS	AGGREGATED SUBREGIONS NETWORK
OHIO REGION 05	501, 502, 503, 505, 505, 506	CLOSED BASINS: NONE 501 503 → 502 504 506 → 505 → 801 507
TENNESSEE REGION 06	601, 602	CLOSED BASINS: NONE 601 → 602 → 505
UPPER MISSISSIPPI REGION 07	701, 702, 703, 704, 705	CLOSED BASINS: NONE 701 → 702 → 703 → 704 → 705 → 801
LOWER MISSISSIPPI REGION 08	801, 802, 803	CLOSED BASINS: NONE 801 → 802 → 803 → GULF OF MEXICO
SOURIS-RED-RAINY REGION 09	901	CLOSED BASINS: NONE 901 → CANADA
MISSOURI REGION 10	1001, 1002, 1003, 1004, 1005, 1006, 1007, 1008, 1009, 1010, 1011	CLOSED BASINS: NONE 1002 → 1003 → 1001 1004 → 1005 → 1006 → 1009 1007 → 1008 → 1011 → 705 1010
ARKANSAS-WHITE RED REGION 11	1101, 1102, 1103, 1104, 1105, 1106, 1107	CLOSED BASINS: NONE 1101 → 801 1102 → 1103 → 1104 → 801 1105 1106 → 1107 → 802
TEXAS GULF REGION 12	1201, 1202, 1203 1204, 1205	CLOSED BASINS: NONE 1201 → GULF OF MEXICO 1202 → GULF OF MEXICO 1203 → GULF OF MEXICO 1204 → GULF OF MEXICO 1205 → GULF OF MEXICO

TABLE 7.2 (cont'd.)

REGIONS	AGGREGATED SUBREGIONS	AGGREGATED SUBREGIONS NETWORK
RIO GRAND REGION 13	1301, 1302, 1303, 1304, 1305	CLOSED BASINS: NONE 1301 → $\left.\begin{array}{l}1302\\1304\end{array}\right\}$ → 1303 → 1305 → GULF OF MEXICO
UPPER COLORADO REGION 14	1401, 1402, 1403	CLOSED BASINS: NONE $\left.\begin{array}{l}1401\\1402\end{array}\right\}$ → 1403 → 1502
LOWER COLORADO REGION 15	1501, 1502, 1503	CLOSED BASINS: NONE $\left.\begin{array}{l}1501\\1503\end{array}\right\}$ → 1502 → MEXICO
GREAT BASIN REGION 16	1601, 1602, 1603, 1604	CLOSED BASINS: 1601, 1602, 1603, 1604
PACIFIC NORTHWEST REGION 17	1701, 1702, 1703, 1704, 1705, 1706, 1707	CLOSED BASINS: 1707 1706 → PUGET SOUND/PACIFIC OCEAN 1703 → $\left.\begin{array}{l}1701\\1704\end{array}\right\}$ → 1702 → 1705 → PACIFIC OCEAN
CALIFORNIA SOUTH PACIFIC REGION 18	1801, 1802, 1803, 1804, 1805, 1806, 1807	CLOSED BASINS: 1807 1801 → PACIFIC OCEAN 1802 → SAN FRANCISCO BAY/PACIFIC OCEAN 1803 → SAN FRANCISCO BAY/PACIFIC OCEAN 1804 → SAN FRANCISCO BAY AND PACIFIC OCEAN 1805 → PACIFIC OCEAN 1806 → PACIFIC OCEAN

TABLE 7.2 (cont'd.)

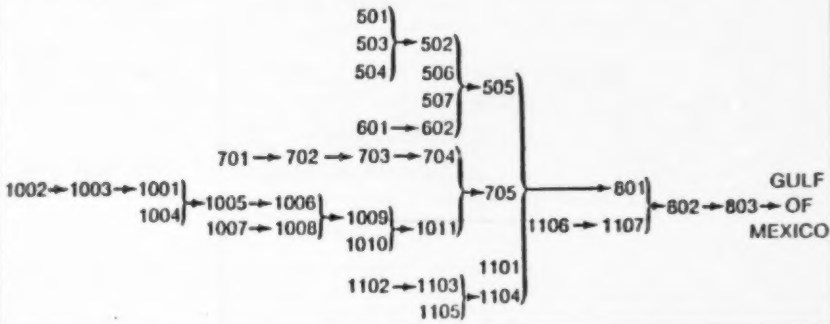
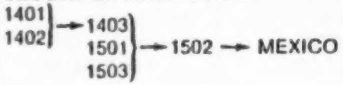
MAJOR DRAINAGE BASINS	AGGREGATED SUBREGIONS	AGGREGATED SUBREGIONS NETWORK
MISSISSIPPI DRAINAGE BASIN OHIO REGION 05 TENNESSEE REGION 06 UPPER MISSISSIPPI REGION 07 LOWER MISSISSIPPI REGION 08 MISSOURI REGION 10 ARKANSAS-WHITE-RED REGION 11	501, 502, 503, 504, 505, 506, 601, 602, 701, 702, 703, 704, 705, 801, 802, 803, 1003, 1004, 1005, 1006, 1007, 1008, 1009, 1010, 1011, 1101, 1102, 1103, 1104, 1105, 1106, 1107	CLOSED BASINS: NONE  501 503 504 502 506 507 505 601 602 701 702 703 704 1002 1003 1001 1004 1005 1006 1007 1008 1009 1010 1011 705 1101 1102 1103 1105 1104 801 1106 1107 802 803 GULF OF MEXICO
COLORADO DRAINAGE BASIN UPPER COLORADO REGION 14 LOWER COLORADO REGION 15	1401, 1402, 1403, 1501, 1502, 1503	CLOSED BASINS: NONE  1401 1402 1403 1501 1503 1502 MEXICO

TABLE 7.3
LIST OF TABLES
FROM THE NATION's WATER RESOUCES, THE SECOND NATIONAL WATER ASSESSMENT BY THE UNITED STATES WATER RESOURCES COUNCIL, STATISTICAL APPENDIX, VOLUMES A-1, A-2, AND A-3

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1	Population, Population Change and Density
2	Employment, Employment Change, and Income Per Capita
3A	Total Earnings, Earnings Change, Earning by Source
3B	Earnings by Source
4	1975 Surface Area Land Use
5	Total Cropland, Changes in Cropland and Cropland Harvested
7	Sheet Erosion by Source and Erosion Change
8A	Total Flood Damages and Change by Land Use
8B	Flood Damages by Land Use
9A	Recreation Requirements
9B	Recreation Requirements
10	Wilderness Areas, Shown Miles and Streams not Meeting Water Quality Standards
11A	Total Electric Power Generation, Change in Total, and Nucleus Portion of Total
11B	Electric Power Generation by Fuel Source
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12B	Discharge of Heat, Biological Oxygen Demand, and Total Suspended Solids of Water
13A	Commodity Origins
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14C	Commerical Navigation
14D	Commerical Navigation
15	Annual Water Supply Data (1975)
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17	Annual Freshwater Imports, Exports, and Net Evaporation
18	Monthly Freshwater Imports, Exports, and Net Evaporation
19	Annual Instream Flow Uses
20	Monthly Instream Flow Uses
21	Annual Water Requirements for Offstream Uses, Average Year
22	Monthly Water Withdrawals by Use, Average Year
23	Monthly Water Consumption by Use
24	Annual Water Requirements for Offstream Uses, Dry Year
25	Monthly Water Withdrawals by Use, Dry Year
26	Monthly Water Consumption by Use, Dry Year
27	Annual Water Withdrawals for Energy Resources Development, Average Year
28	Annual Water Consumption for Energy Resouces Development, Average Year

TABLE 7.3 (cont'd.)

29	Annual Water Withdrawals for Energy Resources Development, Dry Year
30	Annual Water Consumption for Energy Resources Development, Dry Year
31A	Annual Streamflow Depletion Analysis, Average Year
31B	Annual Water Use/Supply Analysis, Average Year
31C	Summary of Monthly and Annual Streamflow Depletion Analyses, Average Month Condition
32A	Monthly Streamflow Depletion Analysis, Average Year
32B	Monthly Water Use/Supply Analysis, Average Year
33A	Annual Streamflow Depletion Analysis, Dry Year
33B	Annual Water Use/Supply Analysis, Dry Year
33C	Summary of Monthly and Annual Streamflow Depletion Analyses, Dry Month Condition
34A	Monthly Streamflow Depletion Analysis, Dry Year
34B	Monthly Water Use/Supply Analysis, Dry Year
35	Average Annual Water Supply Analysis

TABLE 7.4 ANNUAL WATER REQUIREMENTS FOR OFFSTREAM USES[a]

Region/Worst Subregion[b]	1975					
	Public Supply, MGD (1)	Agri-culture, MGD (2)	Industry and Mining, MGD (3)	Steam Elec-tric, MGD (4)	Total Consump-tion, MGD (5)	Steam Electric÷ Total Con-sumption,% (6)
1. New England	213	51	203	21	488	4.30
0103 Mass-Rhode I Coastal	68	18	53	0	139	0
2. Mid-Atlantic	799	310	676	103	1,888	5.46
0202 Lower Hudson-LI-NNJ	341	53	107	0	501	0
3. South Atlantic-Gulf	1,003	3,690	826	153	5,672	2.70
0305 Southern Florida	232	2,411	102	4	2,749	0.15
4. Great Lakes	595	222	1,627	175	2,619	6.68
0403 SW Lake Michigan	104	19	382	50	555	9.01
5. Ohio	416	159	907	324	1,806	17.94
0503 Muskingum-Scioto-Miami	110	26	108	20	264	7.58
6. Tennessee	71	39	163	42	315	13.33
0602 Lower Tennessee	22	20	40	18	100	18.00
7. Upper Mississippi	347	423	285	129	1,184	10.90
0705 Low/Up Mississippi	97	17	69	36	219	16.44
8. Lower Mississippi	344	3,471	520	54	4,389	1.23
0802 Yazoo-Miss-Quachita	82	655	92	11	840	1.31
9. Souris-Red-Rainy	32	73	16	1	122	0.82
0901 Souris-Red-Rainy	32	73	16	1	122	0.82
10. Missouri	490	16,618	245	68	17,421	0.39
1010 Kansas	35	4,190	25	7	4,257	0.16
11. Arkansas-White-Red	374	8,431	338	89	9,232	0.96
1103 Arkansas-Cimarron	64	2,105	79	13	2,261	0.57
12. Texas Gulf	508	10,730	1,127	99	12,464	0.79
1203 Brazos	85	5,282	93	23	5,483	0.42
13. Rio Grande	191	4,353	108	18	4,670	0.39
1302 Middle Rio Grande	115	1,172	12	8	1,307	0.61
14. Upper Colorado	131	2,454	49	43	2,677	1.61
1401 Green-White-Yampa	72	1,029	27	27	1,155	2.34
15. Lower Colorado	253	4,191	205	63	4,712	1.34
1503 Gila	187	3,182	183	12	3,564	0.34
16. Great Basin	467	3,726	52	8	4,253	0.19
1603 Humboldt-Tonopah Desert	149	1,170	12	0	1,331	0
17. Pacific Northwest	455	13,990	343	16	14,804	0.11
1707 Oregon Closed Basin	96	695	0	0	791	0
18. California	1,796	26,218	440	34	28,488	0.12
1803 San Joaquin-Tulare	236	13,245	88	1	13,570	0.01
Conterminous United States	8,485	99,149	8,130	1,440	117,204	1.23

TABLE 7.4 (cont'd.)

Region/Worst Subregion[b]	1985					
	Public Supply, MGD (1)	Agri- culture, MGD (2)	Industry and Mining, MGD (3)	Steam Elec- tric, MGD (4)	Total Consump- tion, MGD (5)	Steam Electric ÷ Total Con- sumption,% (6)
1. New England	232	54	347	18	651	2.76
0103 Mass-Rhode I Coastal	74	18	101	0	193	0
2. Mid-Atlantic	894	402	1,017	224	2,537	8.83
0202 Lower Hudson-LI-NNJ	378	69	151	0	598	0
3. South Atlantic-Gulf	1,223	4,275	1,480	722	7,700	9.38
0305 Southern Florida	302	2,673	168	13	3,156	0.41
4. Great Lakes	655	290	1,894	497	3,336	14.90
0403 SW Lake Michigan	111	25	498	133	767	17.34
5. Ohio	464	194	1,223	656	2,537	25.86
0503 Muskingum-Scioto-Miami	125	28	173	41	367	11.17
6. Tennessee	83	48	287	231	649	35.59
0602 Lower Tennessee	26	25	81	123	255	48.24
7. Upper Mississippi	372	573	366	352	1,663	21.17
0705 Low/Up Mississippi	102	23	104	29	258	11.24
8. Lower Mississippi	373	3,667	804	118	4,962	2.38
0802 Yazoo-Miss-Quachita	88	744	160	35	1,027	3.41
9. Souris-Red-Rainy	33	180	21	0	234	0
0901 Souris-Red-Rainy	33	180	21	0	234	0
10. Missouri	550	20,670	259	243	21,722	1.12
1010 Kansas	37	4,357	33	26	4,453	0.58
11. Arkansas-White-Red	410	8,903	417	237	9,967	2.38
1103 Arkansas-Cimarron	66	2,637	83	12	2,798	0.43
12. Texas Gulf	572	8,761	1,591	270	11,194	2.41
1203 Brazos	88	4,013	105	107	4,313	2.48
13. Rio Grande	209	4,413	144	9	4,775	0.19
1302 Middle Rio Grande	127	1,239	28	7	1,401	0.50
14. Upper Colorado	151	2,966	73	120	3,310	3.63
1401 Green-White-Yampa	81	1,135	36	62	1,314	4.72
15. Lower Colorado	335	4,130	271	134	4,870	2.75
1503 Gila	250	3,114	242	37	3,643	1.02
16. Great Basin	521	3,588	86	44	4,239	1.04
1603 Humboldt-Tonopah Desert	166	1,304	21	16	1,507	1.06
17. Pacific Northwest	538	16,941	520	134	18,133	0.74
1707 Oregon Closed Basin	99	980	0	0	1,079	0
18. California	1,979	27,226	595	101	29,901	0.34
1803 San Joaquin-Tulare	253	14,020	114	26	14,413	0.18
Conterminous United States	9,594	107,281	11,395	4,110	132,380	3.10

TABLE 7.4 (cont'd.)

Region/Worst Subregion[b]	2000 Public Supply, MGD (1)	Agriculture, MGD (2)	Industry and Mining, MGD (3)	Steam Electric, MGD (4)	Total Consumption, MGD (5)	Steam Electric ÷ Total Consumption, % (6)
1. New England	256	59	583	167	1,065	15.68
0103 Mass-Rhode I Coastal	82	19	146	11	258	4.26
2. Mid-Atlantic	1,016	509	1,460	644	3,629	17.75
0202 Lower Hudson-LI-NNJ	428	88	218	0	734	0
3. South Atlantic-Gulf	1,516	4,834	2,882	1,857	11,089	16.75
0305 Southern Florida	414	2,944	326	99	3,783	2.62
4. Great Lakes	720	367	2,267	1,384	4,738	29.21
0403 SW Lake Michigan	116	30	689	290	1,125	25.78
5. Ohio	510	231	1,918	1,692	4,351	38.89
0503 Muskingum-Scioto-Miami	143	31	294	124	592	20.95
6. Tennessee	93	56	541	417	1,107	37.67
0602 Lower Tennessee	29	30	184	236	479	49.27
7. Upper Mississippi	402	710	582	1,079	2,773	38.91
0705 Low/Up Mississippi	110	27	172	66	375	17.60
8. Lower Mississippi	402	3,771	1,483	291	5,947	4.89
0802 Yazoo-Miss-Quachita	93	780	315	121	1,309	9.24
9. Souris-Red-Rainy	33	481	26	0	540	0
0901 Souris-Red-Rainy	33	481	26	0	540	0
10. Missouri	647	20,811	365	644	22,467	2.87
1010 Kansas	38	4,180	58	50	4,326	1.16
11. Arkansas-White-Red	448	8,535	576	457	10,016	4.56
1103 Arkansas-Cimarron	66	2,638	122	11	2,837	0.39
12. Texas Gulf	661	7,094	2,547	994	11,296	8.80
1203 Brazos	93	3,019	118	201	3,431	5.86
13. Rio Grande	224	4,036	174	5	4,439	0.11
1302 Middle Rio Grande	144	1,188	46	4	1,382	0.29
14. Upper Colorado	160	3,061	146	155	3,522	4.40
1401 Green-White-Yampa	87	1,149	70	60	1,366	4.39
15. Lower Colorado	418	3,888	383	126	4,815	2.62
1503 Gila	312	2,835	335	49	3,531	1.39
16. Great Basin	612	3,725	140	52	4,529	1.15
1603 Humboldt-Tonopah Desert	200	1,380	31	15	1,626	0.92
17. Pacific Northwest	630	16,770	907	392	18,699	2.10
1707 Oregon Closed Basin	101	921	0	0	1,022	0
18. California	2,230	28,529	780	242	31,781	0.76
1803 San Joaquin-Tulare	273	15,228	126	87	15,714	0.55
Conterminous United States	10,978	107,467	17,760	10,598	146,803	7.22

TABLE 7.4 (cont'd)

a. Data from The Nation's Water Resources, The Second National Assessment by the U.S. Water Resources Council, Statistical Appendix, Volume A-2. Table 24 - Annual Water Requirements for Offstream Uses, Dry Year

The tabulation includes:

1. Public Supply-

   domestic,
   commericial,
   public lands, and
   fish hatcheries;

2. Agriculture;

3. Industry and Mining - manufacturing and minerals;

4. Steam Electric.

b. The conterminous United States is divided into 18 regions and 99 aggregated subregions defined by hydrologic boundaries. The subregion which has the largest water depletion within a region is listed as the worst subregion. A four digit number is used to identify the subregions. The first two digits identify the region and the last two digits specify the specific subregion.

c. Explanatory Notes

1. For domestic central water supply, it was assumed that per capita usage will remain about constant through the year 2000. This is based on an opinion that actions taken to meet legal requirements and other needs for environmental protection will counteract expansion of demands. Estimates for non-central domestic water uses are based on expectations for increasing per capita use but a declining percentage of the population served. (1)

2. Commercial water is the water used mainly by wholesale and retail businesses not involved in manufacturing or mineral development. A large part of this water is used for cleaning. (1)

3. Water for national parks is mainly to provide water for visitors and developed facilities. Water requirements for public lands and national forests are for all uses thereon. (1)

TABLE 7.4 (cont'd.)

4. Irrigation consumptive use is the crop consumptive use minus effective precipitation. It does not include water for soil salinity control, plant germination, frost protection, erosion protection, or for cooling crops. Incidental consumption associated with irrigation systems has been estimated. Irrigation withdrawals were estimated using efficiency ratios estimated according to irrigation practices in the subregions and limited by available water supply. (1)

5. Manufacturing water use estimates are based on data obtained for 9300 large manufacturing plants by the Office of Business Research and Analysis and on OBERS Series E Projections. The 9300 plants use about 98 percent of the manufacturing water in the United States. (1)

6. Mineral water requirements are based on OBERS Series E Projections and data from the Bureau of Mines. The estimates of water for fuels production and refining do not provide for all possible developments of new energy sources or the possibility that reduced imports of fuels may increase the need for domestic fuel production above the levels projected in OBERS projections. (1)

7. Water for fuels production includes water for fuels extraction and refining of non-petroleum fuels. However, total water requirements for coal liquefaction or gasification and oil shale development are not estimated. (1)

8. Data for steam-electric water uses are based on steam powered generation plants with 25 megawatts or more installed capacities. In general, smaller plants operate for limited periods during the year and use relatively small quantities of water. The data for electric power generation do not include water used for hydroelectric generation which is primarily instream use. Most of the consumption for hydrolectric generation is included in reservoir evaporation. (1)

TABLE 7.5 ANNUAL STREAMFLOW DEPLETION (DRY YEAR)

Region/Worst Subregion	1975					Depletion Ratios	
	Total Stream Flow, MGD (1)	Total Consumption, MGD (2)	Total Depletion, MGD (3)	Minimum Flow, MGD (4)	Available Water, MGD (5)	Total Stream Flow, % (6)	Steam Electric, % (7)
1. New England	63,215	488	485	69,001	-5,786	0.77	0.03
0103 Mass-Rhode I Coastal	3,770	139	-40	4,003	-233	-1.06	0
2. Mid-Atlantic	62,573	1,888	1,375	68,840	-6,267	2.20	0.16
0202 Lower Hudson-LI-NNJ	10,436	501	-957	13,870	-3,434	-9.17	0
3. South Atlantic-Gulf	169,139	5,672	5,338	188,655	-19,516	3.16	0.09
0305 Southern Florida	6,740	2,749	2,674	6,590	150	39.67	0.06
4. Great Lakes	59,823	2,619	2,570	63,951	-4,128	4.30	0.29
0403 SW Lake Michigan	1,395	555	555	875	520	39.78	3.58
5. Ohio	142,805	1,806	1,805	160,520	-17,715	1.26	0.23
0503 Muskingum-Scioto-Miami	9,704	264	264	9,613	91	2.72	0.21
6. Tennessee	36,215	315	315	38,480	-2,265	0.87	0.12
0602 Lower Tennessee	35,999	100	99	38,480	-2,481	0.28	0.05
7. Upper Mississippi	88,405	1,184	-838	110,750	-22,345	-0.95	0.15
0705 Low/Up Mississippi	89,461	219	218	110,750	-21,289	0.24	0.04
8. Lower Mississippi	277,549	4,389	3,975	359,033	-81,484	1.43	0.02
0802 Yazoo-Miss-Quachita	246,457	840	733	319,540	-73,083	0.30	0.00
9. Souris-Red-Rainy	3,498	122	138	3,673	-175	3.95	0.03
0901 Souris-Red-Rainy	3,498	122	138	3,673	-175	3.95	0.03
10. Missouri	46,716	17,421	19,373	33,958	12,758	41.47	0.15
1010 Kansas	3,800	4,257	3,500	3,706	94	92.11	0.18
11. Arkansas-White-Red	38,203	9,232	6,260	46,169	-7,966	16.39	0.23
1103 Arkansas-Cimarron	451	2,261	710	2,867	-2,416	157.43	2.88
12. Texas-Gulf	15,249	12,464	8,561	22,917	-7,668	56.14	0.65
1203 Brazos	632	5,483	2,779	3,360	-2,728	439.72	3.64
13. Rio Grande	4,120	4,670	4,507	2,287	1,833	109.39	0.44
1302 Middle Rio Grande	1,012	1,307	1,090	888	124	107.71	0.79
14. Upper Colorado	11,215	2,677	4,195	7,947	3,268	37.41	0.38
1401 Green-White-Yampa	4,344	1,155	1,664	3,056	1,288	38.31	0.62
15. Lower Colorado	6,910	4,712	7,965	6,864	46	115.27	0.91
1503 Gila	-536	3,564	1,583	676	-1,212	-295.34	-2.24
16. Great Basin	9,984	4,253	3,886	8,177	1,807	38.92	0.08
1603 Humboldt-Tonopah Desert	2,002	1,331	1,138	2,137	-135	56.84	0
17. Pacific Northwest	228,846	14,804	16,140	214,004	14,842	7.05	0.01
1707 Oregon Close Basin	1,221	791	802	1,082	139	65.68	0
18. California	50,750	28,468	22,518	33,130	17,620	44.37	0.07
1803 San Joaquin-Tulare	9,775	13,570	9,825	2,841	-903	100.51	0.01
Conterminous United States	1,315,215	117,204	108,568	---	---	8.25	0.11

TABLE 7.5 (cont'd.)

Region/Worst Subregion	1985					Depletion Ratios	
	Total Stream Flow, MGD (1)	Total Consumption, MGD (2)	Total Depletion, MGD (3)	Minimum Flow, MGD (4)	Available Water, MGD (5)	Total Stream Flow, % (6)	Steam Electric, % (7)
1. New England	63,215	651	652	69,001	-5,786	1.03	0.03
0103 Mass-Rhode I Coastal	3,769	193	-59	4,003	-234	-1.57	0
2. Mid-Atlantic	62,604	2,537	2,057	68,840	-6,236	3.29	0.36
0202 Lower Hudson-LI-NNJ	10,414	598	-853	13,870	-3,456	-8.19	0
3. South Atlantic-Gulf	169,476	7,700	7,706	188,655	-19,179	4.55	0.43
0305 Southern Florida	6,814	3,156	3,156	6,590	224	46.32	0.19
4. Great Lakes	59,850	3,336	3,314	63,951	-4,101	5.54	0.83
0403 SW Lake Michigan	1,394	767	765	875	519	54.88	9.54
5. Ohio	142,475	2,537	2,539	160,520	-18,045	1.78	0.46
0503 Muskingum-Scioto-Miami	9,703	367	367	9,613	90	3.78	0.42
6. Tennessee	36,215	649	646	38,480	-2,265	1.78	0.64
0602 Lower Tennessee	35,822	255	253	38,480	-2,658	0.71	0.34
7. Upper Mississippi	83,715	1,663	-368	110,750	-27,035	-0.44	0.42
0705 Low/Up Mississippi	84,340	258	257	110,750	-26,410	0.30	0.03
8. Lower Mississippi	270,760	4,962	4,963	359,033	-88,273	1.83	0.04
0802 Yazoo-Miss-Quachita	239,071	1,027	1,028	319,540	-80,469	0.43	0.01
9. Souris-Red-Rainy	3,498	234	193	3,673	-175	5.52	0
0901 Souris-Red-Rainy	3,498	234	193	3,673	-175	5.52	0
10. Missouri	49,275	21,722	26,612	33,958	15,317	54.01	0.49
1010 Kansas	5,400	4,453	5,372	3,706	1,694	99.48	0.48
11. Arkansas-White-Red	43,660	9,967	12,696	46,169	-2,509	29.08	0.54
1103 Arkansas-Cimarron	2,649	2,798	3,457	2,867	-218	130.50	0.45
12. Texas-Gulf	20,827	11,194	13,038	22,917	-2,090	62.60	1.30
1203 Brazos	4,399	4,313	5,465	3,360	-1,039	124.23	2.43
13. Rio Grande	4,779	4,775	5,337	2,287	2,492	111.68	0.19
1302 Middle Rio Grande	1,072	1,401	1,444	888	184	134.70	0.65
14. Upper Colorado	11,214	3,310	5,015	7,947	3,267	44.72	1.07
1401 Green-White-Yampa	4,344	1,314	1,982	3,056	1,288	45.63	1.43
15. Lower Colorado	8,504	4,870	10,177	6,864	1,640	119.67	1.58
1503 Gila	1,583	3,643	3,790	676	907	239.42	2.34
16. Great Basin	10,576	4,239	4,392	8,177	2,399	41.53	0.42
1603 Humboldt-Tonopah Desert	2,288	1,507	1,600	2,137	151	69.93	0.70
17. Pacific Northwest	229,475	18,133	20,147	214,004	15,471	8.78	0.06
1707 Oregon Close Basin	1,235	1,079	1,113	1,082	153	90.12	0
18. California	52,947	29,901	26,511	33,130	19,817	50.07	0.19
1803 San Joaquin-Tulare	11,025	14,413	11,195	2,841	8,184	101.54	0.24
Conterminous United States	1,323,065	132,380	145,627	---	---	11.01	0.31

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TABLE 7.5 (cont'd.)

Region/Worst Subregion	2000						
						Depletion Ratios	
	Total Stream Flow, MGD (1)	Total Consumption, MGD (2)	Total Depletion, MGD (3)	Minimum Flow, MGD (4)	Available Water, MGD (5)	Total Stream Flow, % (6)	Steam Electric, % (7)
1. New England	63.216	1,065	1,067	69,001	-5,785	1.69	0.26
0103 Mass-Rhode I Coastal	3,769	258	-61	4,003	-234	-1.62	0.29
2. Mid-Atlantic	62,605	3,629	3,149	68,840	-6,235	5.03	1.03
0202 Lower Hudson-LI-NNJ	10,298	734	-716	13,870	-3,572	-6.95	0
3. South Atlantic-Gulf	169,475	11,089	11,095	188,655	-19,180	6.55	1.10
0305 Southern Florida	6,814	3,783	3,784	6,590	224	55.53	1.45
4. Great Lakes	59,850	4,738	4,721	63,951	-4,101	7.89	2.31
0403 SW Lake Michigan	1,394	1,125	1,125	875	519	80.70	20.80
5. Ohio	142,016	4,351	4,349	160,520	-18,504	3.06	1.19
0503 Muskingum-Scioto-Miami	9,704	592	591	9,613	91	6.09	1.28
6. Tennessee	36,215	1,107	1,105	38,840	-2,625	3.05	1.15
0602 Lower Tennessee	35,587	479	477	38,840	-3,253	1.34	0.66
7. Upper Mississippi	82,142	2,773	754	110,750	-28,608	0.92	1.31
0705 Low/Up Mississippi	81,762	375	374	110,750	-28,988	0.46	0.08
8. Lower Mississippi	265,564	5,947	5,946	359,033	-93,469	2.24	0.11
0802 Yazoo-Miss-Quachita	233,680	1,309	1,309	319,540	-85,860	0.56	0.05
9. Souris-Red-Rainy	3,498	540	-82	3,673	-175	-2.34	0
0901 Souris-Red-Rainy	3,498	540	-82	3,673	-175	-2.34	0
10. Missouri	49,276	22,467	28,196	33,958	15,318	57.22	1.31
1010 Kansas	5,400	4,326	5,298	3,706	1,694	98.11	0.93
11. Arkansas-White-Red	43,662	10,016	12,928	46,169	-2,507	29.61	1.05
1103 Arkansas-Cimarron	2,783	2,837	3,575	2,867	-84	128.46	0.40
12. Texas-Gulf	19,422	11,296	11,852	22,917	-3,495	61.02	5.12
1203 Brazos	4,399	3,431	4,644	3,360	1,039	105.57	4.57
13. Rio Grande	4,779	4,439	5,024	2,287	2,492	105.13	0.10
1302 Middle Rio Grande	1,091	1,382	1,435	888	203	131.53	0.37
14. Upper Colorado	11,214	3,522	5,344	7,947	3,267	47.65	1.38
1401 Green-White-Yampa	4,343	1,366	2,123	3,056	1,287	48.88	1.38
15. Lower Colorado	8,175	4,815	9,947	6,864	1,311	121.68	1.54
1503 Gila	1,583	3,531	3,594	676	907	227.04	3.10
16. Great Basin	10,573	4,529	4,608	8,177	2,396	43.58	0.49
1603 Humboldt-Tonopah Desert	2,288	1,626	1,720	2,137	151	75.17	0.66
17. Pacific Northwest	229,475	18,699	20,733	214,004	15,471	9.03	0.17
1707 Oregon Close Basin	1,235	1,022	1,062	1,082	153	85.99	0
18. California	52,949	31,781	28,586	33,130	19,819	53.99	0.46
1803 San Joaquin-Tulare	11,025	15,714	12,017	2,841	8,184	109.00	0.79
Conterminous United States	1,314,106	146,803	159,322	---	---	12.12	0.81

TABLE 7.5 (cont'd.)

Data from *The Nation's Water Resources, The Second National Assesment by the U.S. Water Resources Council, Statistical Appendix, Volumes A-2 and A-3.*

Definitions:

Total Stream Flow in Hydrologic Unit (col. 1): (Future Stream Flow at Outflow Point*) (Total Depletion, col. 3)

Total Consumption in Hydrologic Unit (col. 2): from col. 5, Table 7.4, this report

Total Depletion in Hydrologic Unit (col. 3): (Consumption Requirements) in Hydrologic Unit*) + (Exports^{+}) - (Imports^{+}) + (Evaporation^{+}) - (Ground Water Mining*)

Minimum Flow (col. 4): from Table 19, see explanatory note 3

Available Water (col. 5): (col. 1) - (col. 4)

Total Stream Flow Depletion Ratio (col. 6): (col. 3) ÷ (col. 1)

Steam Electric Depletion: (col. 4, Table 7.4) ÷ (col. 1)

+ Table 17-Annual Freshwater Imports, Exports, and Net Evaporation

* Table 33A - Annual Stream Flow Depletion Analysis, Dry Year

Explanatory Notes

Table 17 - Annual Freshwater Imports, Exports, and Net Evaporation (Vol. A-2)	1. Imports and exports refer to artificial transfers of freshwater from one subregion to another. (1)
	2. Net evaporation is evaporation exceeding precipitation on water surfaces. Reservoir evaporation data are for major reservoirs exceeding 5,000 acre-feet (1.63 billion gallons) storage capacity. Farm stock pond evaporation data are for small on-farm ponds and reservoirs. (1)
Table 19 - Annual Instream Flow Uses (Vol. A-2)	3. Instream flow approximations (IFA) for fish and wildlife are based on judgmental estimates of streamflow required at subregional outflow points to maintain habitat for aquatic and riparian plants and animals. These data are only for the National Water

TABLE 7-5 (cont'd.)

Assessment. Additional studies are needed to obtain better data for state, region, and subregion planning. (1)

Table 33A - Annual Stream Flow Depletion Analysis, Dry Year (Vol. A-3)

4. Total Streamflow: This is an estimate of how much water would be flowing in the stream if consumption and ground water mining were stopped in the hydrologic unit under consideration. It assumes that imports, exports and net evaporation are not recoverable.

5. Consumption Requirements in Hydrologic Unit: Offstream uses require diversion or withdrawal of water from its natural body or stream. Many such uses result in a portion of this water being discharged to the atmosphere as vapor or steam. When this discharge is caused by human activity, it is called consumption in this Assessment. (1)

6. Total Depletion (col. 3): The man induced impacts taken equal to the actual consumptive use + net evaporation + exports - imports (within the hydrologic unit).

7. Minimum Flow (col. 4): This is a minimum flow desired from the fish and wildlife standpoint and is based on judgmental estimates of streamflow required at subregional outflow points to maintain habitat for aquatic and riparian plants and animals. This flow is only for the National Water Assessment and is not adjusted for dry year conditions.

8. Available Water (col. 5): This is calculated by subtracting the Minimum Flow for fish and wildlife from the Total Stream Flow and it gives an indication as to how much water is left for human consumption in a given region. Negative values as well as positive values which are less than

TABLE 7.5 (cont'd.)

the Consumption Requirements indicate that, in dry years, the minimum flow for fish and wildlife cannot be maintained while also satisfying human consumption.

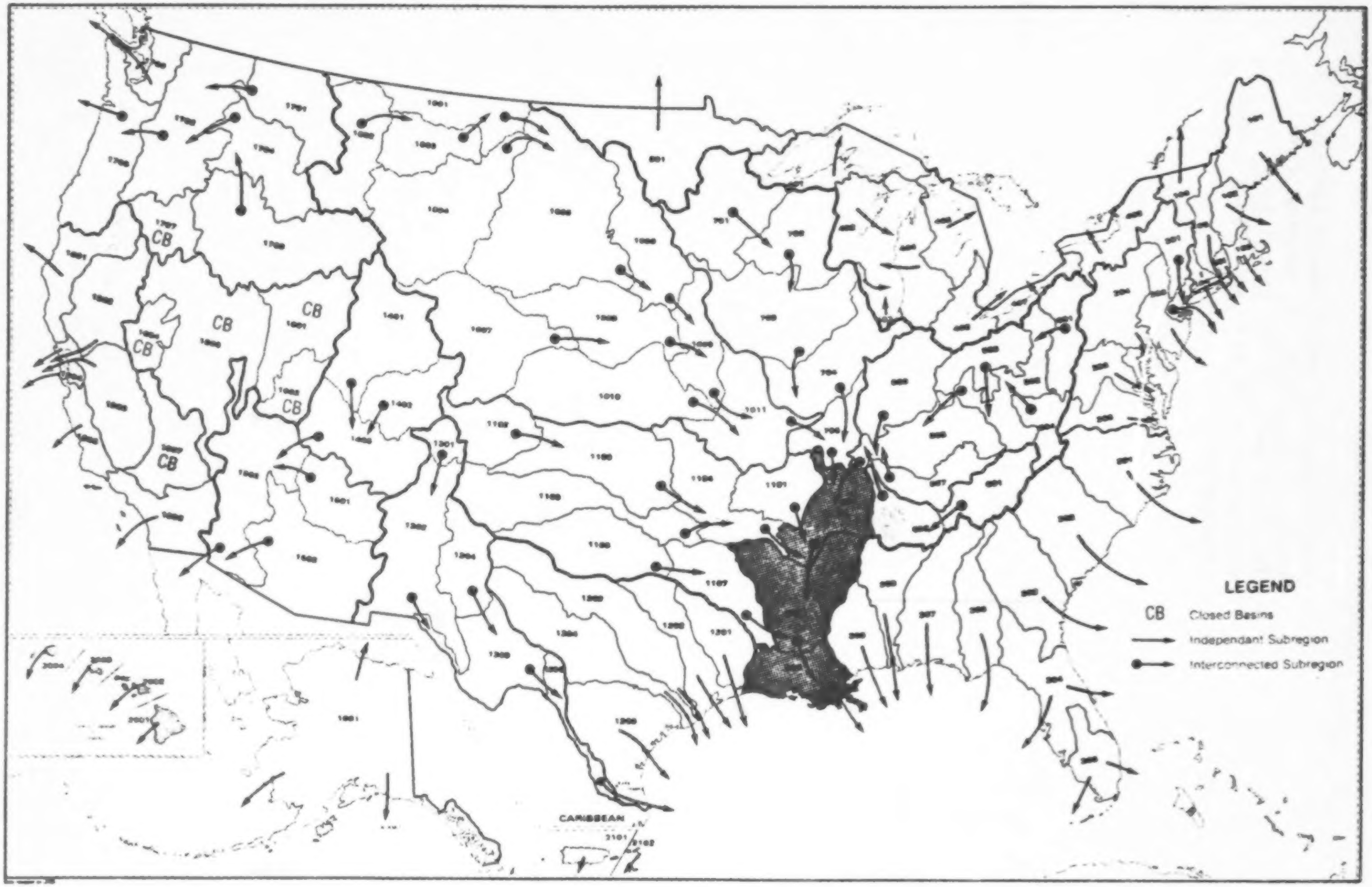
LEGEND
CB Closed Basins
Independant Subregion
Interconnected Subregion
CB
CB
CB
CB
CB
CB
CARIBBEAN
2101
2102

Figure 7.1 Water Resource Regions and Flow Patterns for Aggregated Subregions

SECTION 8

LEGAL CONSTRAINTS AND THEIR IMPACT ON CONSUMPTIVE WATER USE

8.1 INTRODUCTION

To determine the availability of water for consumptive use by power systems, it is first necessary to examine the laws and regulations that govern water allocation and use. Although water may be physically available in a certain area, the legal right to its use is the first determinant as to its availiability for a particular use. There is no clear way of classifying all the differing laws and accompanying rules, regulations and regulatory guidelines and court decisions as they apply to waters of the United States for they vary from agency to agency and from state to state with the final arbitrator being the courts.

Laws and regulations that govern water availability on a Federal level are based on the need to protect our environment for future generations and the availability of present and future resources. Following are the major regulations that govern the allocation of water resources and seek to protect the environment.

This section gives a brief overview of major features of the institutional framework within which water for energy conversion uses will be sought and developed. The features described include the constitutional basis for water laws and some of the more important Federal statutes, international treaties and interstate compacts. The potential impacts of Indian water rights, Federal water rights and state water law and policy are also included. Other institutional considerations not included but which will require consideration are relationships to on-going and completed water resources development plans of Federal, state, and regional agencies.

Table 8-1 at the end of the section gives, on the basis of the 18 water resource regions: 1) the major rivers in the conterminous United States, 2) the known compacts or treaties on those water bodies, 3) the minimum flows at the outflow points of certain rivers, and 4) the parties affected by these treaties or compacts and the water apportionment among the various states in some cases. For those compacts and treaties that are too complex to list in tabular form, reference is made to the sources where they can be found.

8.2 FEDERAL AUTHORITIES

Federal water program and water rights are carried out under a number of the provisions of the Constitution of the United States. For example, water programs may be carried out with reliance on the Federal authority to make treaties under Article I, Section 10, and Article II, Section 2, or under Article I, Section 8 of the Constitution which concerns national defense. Another authority for Federal activity may be the power to provide for the general welfare under Article I, Section 8.

With respect to Federal water programs, perhaps the best known constitutional power is that contained in Article I, Section 8 conferring authority to regulate commerce with foreign nations and among the states. This section draws a distinction between navigable and non-navigable waters, a distinction having importance both for purpose of property rights in and public regulatory authority over water.

Article I, Section 10 of the Constitution provides that a state may not enter into an agreement or compact with another state without the consent of Congress. For apportioning the waters of interstate streams, the most common device used is the interstate compact negotiated by basin states and approved by Congress.

States unable to agree upon an apportionment, or not desiring to negotiate an agreement, may resort to litigation before the Supreme Court. In this instance, it is the judicial decree that operates to control each state's development and use of water from an interstate stream. In some cases, the compact creating the Delaware River Basin Commission (DRBC) is an example, the court decree has been incorporated into a subsequent compact providing a mechanism for modifying the operative effect of the terms of the decree.

The third procedure for apportioning interstate waters among the states is by Act of Congress. The constitutional basis for such action may be unclear, and this action has been used on a limited basis in one instance. There Congress merely determined how much water each contending state should receive through Federal facilities operated by the Department of the Interior (DOI).(1)

It is important to remember that the apportionment of interstate streams, whether by compact between the states, judicial decree, or Act of Congress, is merely a quantification of property rights to use the waters of the streams. These property rights are subject and subordinate to the superior Federal power to regulate navigation on such interstate streams.

The following is an alphabetical listing of Interstate Compacts (2) and their dates of introduction:

Arkansas River Compact, 1948
Arkansas River Basin Compact, 1965
Bear River Compact, 1955
Belle Fourche River Compact, 1943
Canadian River Compact, 1950
Colorado River Compact, 1922
Connecticut River Flood Control Compact, 1951
Costilla Creek Compact, 1963
Delaware River Basin Compact, 1961
Great Lakes Basin Compact, 1955
Klamath River Basin Compact, 1957

La Plata River Compact, 1922
Merrimack River Flood Control Compact, 1956
New England Interstate Water Pollution Control Compact, 1947
New York Harbor (Tri-State) Interstate Sanitation Compact, 1935
Ohio River Valley Water Sanitation Compact, 1939
Pecos River Compact, 1948
Potomac River Basin Compact, 1939
Red River of the North Compact, 1937
Republican River Compact, 1942
Rio Grande Compact, 1938
Sabine River Compact, 1953
Snake River Compact, 1949
South Platte River Compact, 1923
Susquehanna River Basin Compact, 1970
Tennessee River Basin Water Pollution Control Compact, 1955
Thames River Flood Control Compact, 1957
Upper Colorado River Basin Compact, 1948
Wheeling Creek Watershed Protection and Flood Prevention District Compact, 1967
Yellowstone River Compact, 1950

8.3 FEDERAL STATUTES

Numerous Federal statutes have been enacted which affect and, in many cases, control the development of water resources in the United States. The more significant laws are considered here as an overview to the legislation that governs water availability.

8.3.1 Rivers and Harbors Act of 1899, (33 USC 401-411)

The Act provides that the Army Corps of Engineers must approve plans for construction, excavation, filling or removal of obstructions in navigable waterways of the United States. It further prohibits the deposit of refuse in navigable waters generally and was thus referred to commonly as the Refuse Act of 1899. The Act forms the base for all other environmentally-related legislation in the U.S.

8.3.2 Reclamation Act of 1902, (P.L. 57-161)

The Act introduced Federal financing for large dams and irrigation projects since these could not be fully met by private capital. A revolving fund was established with moneys received from the sale of public lands, and the Secretary of the Interior was directed to survey the west and locate and construct irrigation projects, opening the improved public lands to settlement under the homestead laws. Where private lands were included within the area irrigable by project works, water rights might be sold to the landowners for irrigation of tracts not exceeding 160 acres.

8.3.3 Federal Water Power Act of 1920, as amended (P.L. 66-280)

The Act created the Federal Power Commission (now Federal Energy Regulatory Commission) which licenses non-Federal hydroelectric power projects located on navigable streams or streams over which the Congress has jurisdiction because the project affects interstate commerce or on public lands or reservations of the United States. The Commission can impose development and operational conditions as determined necessary to protect the public interest. Further, the Commission conducts studies and investigations of potential hydroelectric sites and makes projections of electric power requirements and supply.

8.3.4 Fish and Wildlife Coordination Act of 1958, (P.L. 85-624)

The provisions of this Act govern the protection and propagation of fish and wildlife in connection with Federal projects or Federally-permitted activities. The provisions of the Act apply to the control or modification of the waters of any stream or other body of water by an agency or department of the United States or by any public or private agency acting under a Federal permit or license. The impacts of altered runoff and sedimentation from strip-mining may be of concern here.

8.3.5 Wilderness Act of 1964, (P.L. 88-577)

About 11 million acres of Federal lands have been designated as part of the Wilderness Preservation System established under the Act. Large additional areas are under consideration for inclusion into the System. Incompatible land and water uses and activities are precluded in much of the area in the absence of specific congressional authorizing action. This includes the development of water storage reservoirs and water conveyance facilities. Many of the best remaining undeveloped dam and reservoir sites, from a physical and economic veiwpoint, are within these designated areas.

8.3.6 Water Resources Planning Act of 1964, (P.L. 89-80)

This Act created the Water Resources Council (3), composed of the Secretaries of Interior; Argiculture; Army; Health, Education, and Welfare; and Transportation; and the Chairman of the Federal Power Commission (now Federal Energy Regulatory Commission). Associate members include the Secretaries of Commerce and of Housing and Urban Development, and the Deputy Administrator of the Environmental Protection Agency. A principle objective of the Council is to coordinate the planning for water and related land resources by the several Federal agencies and to encourage the conservation, development and utilization of those resources on a comprehensive and coordinated basis by Federal, state and local governments and private enterprise.

Under this Act, river basin commissions, composed of representatives of the Federal agencies and of the states involved, are authorized to prepare plans for the water and related land resources of the respective areas. A river basin commission is prohibited by the statute from considering any water resources outside its particular area, thus precluding it from planning an interbasin transfer into its area. Several such commissions have been formed, namely:

Great Lakes Basin Commission
Missouri River Basin Commision
New England River Basins Commission
Ohio River Basin Commission
Pacific Northwest River Basins Commission
Upper Mississippi River Basin Commission

Presently, the Council is completing the 1975 Assessement. This document is designed to identify and describe the Nation's severe water and water-related problems. The only previous national assessment, completed in 1968, identified the then emerging problems. The new assessment will identify these problems in more geographical detail and with greater regional emphasis.

8.3.7 Wild and Scenic Rivers Act of 1968, as amended (P.L. 90-542)

A National Wild and Scenic Rivers System was established by this statute with eight rivers or reaches of rivers initially designated as components of the system to be maintained in a free-flowing state. Additional rivers or river reaches can be added to the system, and a large number are now under study, with a number of bills for inclusion pending in Congress. There is a substantial hydroelectric power potential in these river reaches which at this time cannot be developed.

8.3.8 Colorado River Basin Project Act of 1968, (P.L. 90-537)

This Act authorized construction of the Central Arizona Project and several smaller projects. The Project is subject to the specified prior rights of California and Nevada. Planning by Federal agencies for interbasin transfers into the Colorado River Basin from drainage outside the Basin States is prohibited. The Act, however, states an objective to provide a program for the comprehensive development of the water resources of the Colorado River Basin and for the provision of additional water supplies for use in the Upper as well as in the Lower Colorado River Basin. It further provides that satisfaction of the Mexican Water Treaty of 1944 for the Colorado River will become a national obligation under any program for augmentation of the water supplies of the Colorado River Basin in amounts of 2.5 million acre-feet per year or more. The Act also withdrew the Federal Power Commission's hydroelectric licensing authority for the Colorado River between Hoover Dam and Glen Canyon Dam.

8.3.9 National Environmental Policy Act of 1969, (P.L. 91-190)

Under the provisions of this statute, the short-and long-term environmental consequences of a proposed Federal program, project, or other action affecting the environment must be evaluated and set forth in an Environmental Impact Statement. Alternatives to the proposed action must be fully considered and evaluated.

8.3.10 Federal Water Pollution Control Act Amendments of 1972, (P.L. 92-500)

This comprehensive Act covers the disposal of pollutants from any man-made or man-induced source or cause, including those from Federal installations to navigable waters which are defined for the purposes of the Act as being all waters. The Act directly controls the development and utilization of new water for energy production and the disposal of waste products, including heat. The Act provides for the Environmental Protection Agency to establish effluent limitations on point source discharges and to administer a system of permits for pollutant discharges. Intakes and point identifiable and non-point unidentifiable sources of discharges are both regulated under different sections of the Act. Federal permits may not be required in states which have received authority from EPA to issue and enforce permits meeting the requirements of the Act. EPA, however, retains the power to intercede in the permitting actions of the delegated states.

8.3.11 Marine Protection, Research and Sanctuaries Act of 1972, (P.L. 92-532)

Ocean dumping is allowed only in accordance with permits issued by the Environmental Protection Agency or the U.S. Army Corps of Engineers for dredged materials. Permits will be issued where it has been determined that the dumping will not unreasonably degrade or endanger human health, welfare or amenities, or the marine environment, ecological systems, or their economic potentials.

8.3.12 Coastal Zone Management Act of 1972, (P.L. 92-583)

Under this Act, the Secretary of Commerce is directed to cooperate with the coastal and Great Lakes States, including provision of Federal financial grants, in the development and implementation of plans and programs for management of the land and water resources of the coastal zone. The national policy is "...to preserve, protect, develop and, where possible, to restore or enhance, the resources of the nation's coastal zone for this and succeeding generations...."

8.3.13 Federal Water Project Authorization Acts

The statutes authorizing the construction of Federal water projects usually describe the works to be built in general terms, and specify the functions, areas and water uses to be served by the project. The functions and water uses include navigation, flood control, hydro-power generation, municipal and industrial water supply, irrigation, fish and wildlife enhancement, recreation and water quality control or low flow augmentation. These acts then, in effect, commit both the developed water and the reservoir storage capacity to the specified purposes. Any significant changes to facilitate the production and/or use of energy would require further congressinal action.

The contracts executed by non-Federal interest with the United States for the purchase of water and energy developed by Federal projects are long-term and subject to renewal upon mutually acceptable terms.

Major Federal projects have been built on many of the major streams of the western states and on several eastern streams. Thus, a large proportion of the water resources and of the reservoir storage capacity of these States have been committed by Federal statutes and by contracts executed in furtherance thereof.

8.3.14 Endangered Species Act of 1973, (P.L. 93-205)

The purposes of this Act are to provide a means whereby the ecosystems upon which endangered species and threatened species depend may be conserved and to provide a program for the conservation of such endangered and threatened species.

8.3.15 Other Federal Enactments

There are many other Federal laws concerning the development and use of water and related land resources which are relevant to the subject of this report, including but not limited to:

1. The several flood control acts

2. Public lands statutes

3. Federal Water Project Recreation Act

4. Water Supply Act of 1958

8.4 INTERNATIONAL TREATIES

Most streams flowing across or forming the boundaries of the United States and the Great Lakes are subject to international agreements with Canada or Mexico. The treaties of particular significance to energy considerations include those listed below (1).

8.4.1 The Mexican Water Treaty of 1944

This treaty covering the Colorado River and Rio Grande River, as well as the Tiajuana River and other streams, is administered by the International Boundary and Water Commission. Under it, the United States is obligated to deliver to Mexico at least 1.5 million acre-feet per year of Colorado River water.

8.4.2 Colorado River Basin Salinity Control Act (P.L. 93-320)

Under this recent agreement which implements Minute 242 of the 1944 Treaty, the United States authorized the construction, operation and maintenance of certain works in the Colorado River Basin to decrease the salinity of the Colorado River water flowing into Mexico. Among other things, Minute 242 provides that the United States shall adopt measures to assure that the approximately 1,360,000 acre-feet of the Treaty water annually delivered to Mexico upstream of Morelos Dam have an average salinity of no more than 115 ppm ± 30 ppm over the average salinity of the Colorado River water arriving at Imperial Dam (4).

8.4.3 The Treaty of 1909 with Canada

The International Joint Commission functions under this treaty and has responsibilities regarding the international waters from Lake of the Woods in Minnesota to eastern Maine.

8.4.4 Columbia River Treaty with Canada

The treaty arrangements in the Columbia River Basin, particularly as regard the Libby Dam and upstream storage reservoirs in Canada, are embodied in this agreement.

8.5 INTERSTATE COMPACTS

Numerous interstate compacts have been executed by the states and approved by Congress, apportioning the waters of interstate streams, particularly in the West. The waters are generally apportioned among the states and each state is then left to allocate its share of the water among intrastate users on the basis of its own system of water rights. Some important examples of such compacts which must be considered in assessing the availability of water for energy are noted in the following sections.

8.5.1 The Colorado River Compact of 1922

This compact apportioned the waters of the Colorado River at Lee Ferry between the Upper Basin States (Colorado, New Mexico, Utah and Wyoming) and the Lower Basin States (Arizona, California and Nevada). The Upper Colorado River Basin Compact of 1948 apportioned the Upper Basin allocation among the Upper Basin States. Apportionment of the Lower Basin allocation among the three states has been the subject of extensive litigation.

8.5.2 The Delaware and Susquehanna River Basin Compacts

These compacts are unique in that they do not apportion water. However, each requires that any project or development which will make significant use of basin waters be submitted to the commission established by the compact for review and approval. This applies to projects for power production and processing of energy resources as well as to other uses. It should be noted that the Delaware and Susquehanna Compacts are Federal-interstate rather than merely interstate agreements. Consequently, the United States and the basin states are parties, and all are represented on the commissions that have approval authority.

8.6 INDIAN WATER RIGHTS

In areas where there are Indian reservations, Indians have a special status. The reservations exist, are governed by and have rights by treaty with the United States. In general, these treaties confer upon the Indians on the reservation enough water from the water resources available to permit them to follow their normal way of life.

A complex and sometimes unclear body of law has developed through decisions of the Supreme Court concerning the ability and restrictions to transfer Indian rights to non-Indians, even by sale for good value received.

In any event, the status of Indian rights as treaty rights gives them the protection of the Supremacy Clause of the United States Constitution (Article VI, Section 2). Accordingly, state laws which normally govern the aquisition, vesting and transfer of water rights have little or no applicability to Indian water rights. These rights exist outside the established system for the appropriation of water.

8.7 FEDERAL WATER RIGHTS

While there is no single body of water rights laws at the Federal level, it seems clear that the United States has certain, although imperfectly formed and unquantified, rights to water and control over water resources. These are apart from the rights which have been acquired for specific Federal projects pursuant to state laws. The principal bases for these apparent rights include the reservation doctrine and the concept of navigation servitude.

8.7.1 Reservation Doctrine

Under this doctrine, it is maintained that when the United States reserved or removed public lands of the United States from entry, it also removed from appropriation by others the waters originating on or flowing across such reserved or removed lands. These include the national forests, national parks, power site withdrawals, reclamation withdrawals and the like. Most of these land reservations and water withdrawals were made late in the 19th Century. Rights of the United States under the reservation doctrine are subject only to those prior rights of others which had become vested by the time of the reservation or withdrawal.

No attempt has yet been made to quantify these reserved Federal water rights or to determine the extent of the uses to which they may be put. It is generally presumed that enough water has been reserved to make Federal operation of the land effective for whatever legitimate purposes the United States may intend, either at the time that the reservation is made or when the eventual use is actually undertaken.

While the reservation doctrine is identified with the West, theoretically, there is no bar to its being used in connection with Federal land holdings in other parts of the country. So far, the principal reason why this may not have occurred is that it has generally been true that locally available water was sufficient to meet all needs.

Whatever actual water rights the United States may have under the Reservation Doctrine, they are extremely important. Vast acreages of Federally owned land exist, not subject to entry and particularly in the West, with many valuable resources as yet undeveloped. These resources are not limited to those essential for energy production. In several areas of the West, the Great Basin for example, the available water resources are not adequate for full development of the other resources of the public domain. Difficult policy decisions will be necessary to allocate the available water resources among the competing needs.

Full exercise by the United States of its reserved rights in regions with limited water resources would inevitably conflict with the rights of others acquired under state law and the beneficial uses of water under those rights. The means of resolution of those conflicts have not yet evolved.

8.7.2 Federal Power over Navigation under the Commerce Clause

On the navigable waters of the United States, which constitute by far the greater part of all water in the country other than groundwater, the Federal Government has virtually complete regulatory control, if it wishes to exercise it. This is due to the congressional power over interstate and foreign commerce which is held to include navigation. The Federal regulatory authority might be used in favor of power generation or for other purposes which might compete with it for an available water supply. To date, however, the United States has not fully exercised its rights under the doctrine of navigation servitude on any major stream.

8.8 STATE WATER LAWS AND POLICIES

All of the states have enacted and have provided the organizational structure to implement some measure of state control over water use. All states, for example, have enacted water pollution control legislation which is generally implemented in cooperation with the Environmental Protection Agency. Some of the state water quality control laws, California for example, are very stringent and cover all forms and causes of water quality impairment for all waters of the State. Each of the western states has a well-developed body of statutory law and procedure for the acquisition and the administration of water rights. More and more eastern states are enacting statutes and adopting procedures governing water rights. Most of these water rights laws concern only surface waters. A few states, Utah for example, have statutes controlling ground water use.

California and a considerable number of other states have enacted environmental protection statutes similar in intent to the National Environmental Policy Act of 1969. California has also created a Wild and Scenic Rivers System which encompasses all of the remaining undeveloped water resources of the North Coastal Region where about 41 percent of the state's water resources originate. Oregon has allocated a significant portion of its water resources to instream uses such as fish and wildlife. Other states have similar enactments.

In the western states, the highest priority for water use is generally accorded to municipal and domestic supplies, followed by irrigation and industrial supplies. Some but not all state water laws provide for the allocation of water for instream uses.

The laws of some states, Nebraska for example, impose severe restrictions on inter-basin transfers. Some state water laws contain provisions for the protection of the basins of origin.

State water laws and policies will necessarily be a major consideration in the planning and development of new water supplies for energy production. Any attempt to override state statutes and authority is apt to be met with vigorous opposition and litigation.

8.8.1 State Water Rights

8.8.1.1 Surface Water Rights--

There are two doctrines of water rights which prevail in the United States: riparian and appropriation. The riparian doctrine has been followed in eastern states but is gradually giving way to statutes imposing a modified appropriative system. The appropriation doctrine originated in the western states in the early mining days and forms the basis of western water rights law. A few western states, including Texas, California, and Hawaii, have dual systems of water rights.

8.8.1.1.1 Riparian Rights--

The rights of an owner of riparian land exist because the parcel abuts and remains in contact with the stream. A riparian right is not created by use nor lost through non-use. Use of water under the right must be reasonable in relation to the use by other riparian owners and only on the riparian land. Strictly interpreted, the riparian user could not destroy, materially diminish, or alter the quality or quantity of the water flowing to downstream riparian owners. Riparian rights can be sold and transferred but only for use on other lands which qualify as riparian, and the purchaser remains subject to the same reasonable use restrictions which applied to the seller.

8.8.1.1.2 Appropriative Rights--

Appropriative rights are now acquired by following the procedures prescribed by state statutes. The priority of an appropriative right in relation to other appropriative rights is generally the date the application for the right was filed with the state agency administering water rights. The right becomes finally vested upon full application of the water to beneficial uses. The right can be lost through non-use or abandonment.

The first person to initiate a water use has the first or prior right over all subsequent users of water from a given stream. Two commonly heard expressions are: "first in time is first in right", and "beneficial use is the basis, measure, and limit of the right." The method of acquiring appropriative water rights varies from state to state. The following general characteristics apply in various degrees to the administration and acquisition of water rights in western states (5).

> Administrator. In most western states, the administration of water resource responsibilities is performed by an official, normally called the "State Engineer." Some states have given this responsibility to a commission or board that supervises this administrative officer who keeps records of water use; receives applications for water rights, reviews them, and registers his approval or denial; appoints river commissioners or water masters to supervise water distribution according to priority of right; and institutes court actions to determine and adjudicate water rights.
>
> Filing. A water user is required by statute to express his intention to appropriate water for beneficial consumptive use by filing an application with the proper state officer or agency. This does not apply in Colorado and Montana.
>
> Protest and Hearing. After an application has been filed, a holder of a water right who feels he may be injured if a right to use water were to be granted to the new applicant may file a protest. The state administrator or agency will then hold a hearing at which interested parties may be heard.

Approval of Filing. If the state officer or agency determines that there is unappropriated water in the stream or other source that can be put to beneficial use by the applicant without impairing prior existing rights, the filing to appropriate is approved. If the appropriation of water is not permitted, the applicant may appeal to a state district court.

Perfection of Right. After approval of filing, the applicant proceeds to perfect his water right by constructing the necessary storage, diversion and conveyance works and by applying the water to beneficial use.

Certification. After the state administrator is satisfied that the applicant has perfected his right, a certificate or other document is issued by the state to the appropriator as prima facie evidence of the water right.

Ground Water. If the water code of the state includes all waters, both surface and undergound, similar statutory procedures will generally apply to the appropriation and use of both. This rule is not universal because some states still treat surface and ground water differently.

Statutory Adjudication of Rights. In order to provide a coordinated and integrated decree encompassing and defining all rights to the use of water from a common source, almost all western states have enacted statutory adjudication procedures. These actions may be initiated in a state or Federal district court by water users, state or Federal officials. The result is a determination of the relative rights of all water users for a given stream or other water source.

Sales, Transfers, Changes. Appropriation water rights may be sold and transferred, either with the sale of the land upon which the water is used, or separately under procedures peculiar to each state. Changes in a water right might involve a change in the point of diversion of water from the stream, in the manner of use, purpose of use, or place of use. These changes can be made only after proper application to the state administrator and his careful review and approval under well-defined rules that differ from state to state. The basic concern with a change is that the alteration not be detrimental to other water rights.

Water Contracts. Rights to use water can also be acquired through contractual arrangements between the owner of a water right and another party desiring to use all or part of the water covered by that right. These arrangements are governed by the contract laws. For instance, in the western states the Federal Bureau of Reclamation may acquire a water right directly from

> the state or by assignment from a water conservancy or irrigation district that has already obtained a water right. This right is usually to a supply that must be regulated by a storage reservoir. The Bureau, after constructing a reservoir, wholesales water by contract to a water district or municipality. Pursuant to delivery contracts executed with water users, these entities retain the water.

The above discussion on appropriation of water rights is quite general. Specific procedures vary in many ways from state to state, particularly with regard to details. Furthermore, in recent years the application of water to beneficial use in the public interest, which is basic to the appropriation concept, has been broadened in some states by legislative guidelines that recognize the use of water for instream flows for fish and wildlife, aesthetics, recreation, and other social values. These laws also are peculiar to each state.

8.8.1.2 Ground Water Rights--

The administration of ground water rights varies widely among the states from no regulation to complete regulation of ground water use. In any event, many ground water basins and aquifers in the country have been developed to some extent, and the rights to use ground water have become vested through use. There are a number of legal doctrines relating to ground water rights, varying from the "rule of capture" which was upheld by the Texas Supreme Court to the "correlative doctrine" and "mutual prescription doctrine" approved by the courts of California (6).

Some narrowly confined aquifers have been treated as "underground streams," and the law of surface streams is applied to them. Most ground water in aquifers, however, is so physically different from water in streams that historically it was treated differently. The first rule concerned ownership; the land owner was regarded as owning the water underneath his land and was permitted to take whatever quantity he could capture. A number of state courts then imposed requirements that the owner's use of ground water must be reasonable and connected with use of the overlying land. Some courts have applied a rule of correlative rights similar to riparian doctrines of reasonable sharing. Many have superimposed substantial statutory regulation on the exercise of these common law doctrines. A number of western states now have statutes adapting rules of prior appropriation to ground water.

The ownership rule is in force in the following 10 states:

Connecticut
Maine
Massachusetts
Mississippi
New Jersey
Ohio
Rhode Island
Texas
Vermont
Wisconsin

The reasonable use rule if followed in these 16 states:

Alabama
Arizona
Illinois
Indiana
Iowa
Kentucky
Maryland
Michigan
Missouri
New Hampshire
New York
North Carolina
Pennsylvania
Tennessee
Virginia
West Virginia

In some of the above states, the rule followed is not totally clear or classification is based on judicial opinion. Lousisiana has a rule of capture based on Civil Code.

Correlative rights are the rule in:

Arkansas
California
Nebraska

Permit systems seem to supersede common law rules in the following:

Nebraska
New Jersey
New York
North Carolina
Wisconsin

Fourteen states apply the law of prior appropriation. Five of these states, listed below, use the same law applicable to surface streams.

Alaska
Kansas
Montana
North Dakota
Utah

Separate ground water codes are found in nine of these states:

Colorado
Idaho
Nevada
New Mexico
Oklahoma
Oregon
South Dakota
Washinton
Wyoming

In addition, ground water districts which exercise many controls on withdrawals exist in:

California
Colorado
Florida
Nebraska
New Mexico
Texas

8.8 DIVISION OF STATES ACCORDING TO WATER RIGHTS LAWS OBSERVED

Many western streams are already grossly overappropriated in terms of the sum of claimed amounts under vested appropriative rights, although in fact there may still remain some unused water, particularly during the nonirrigation season. Overappropriation will add to the difficulties of obtaining water rights for new uses related to energy and in transferring existing rights.

States maintaining pure appropriation law or "Colorado Doctrine," which has existed from their beginnings, are:

Alaska
Arizona
Colorado
Idaho
Montana
Nevada
New Mexico
Utah
Wyoming

Some states recognize both riparian and appropriation rights; however, all of these are substantially "appropriation states" in that law is the most important today. In these states, riparian rights are the historical basis of some uses but all new uses are appropriative. However, only in California and to a limited extent Nebraska are there possibilities of initiating new water uses by exercising riparian rights. Dual rights states are:

California
Kansas
Mississippi
Nebraska
North Dakota
Oklahoma
Oregon
South Dakota
Texas
Washington

It would be misleading to say that the water law of the other 31 states is common law riparianism. Some of these states permit non-riparian uses as well. Nine, those listed here, control the initiation of substantially all new uses by administrative permits:

Delaware
Florida
Iowa
Kentucky
Maryland
Minnesota
New Jersey
North Carolina
Wisconsin (agriculture & mining)

The remaining mainland states may have the doctrine of riparian rights as their common law, but it has been heavily overlaid with statutes which control dams on navigable streams,hydroelectric dams or all dams; statutes which authorize non-riparian use of water stored in dams; statutes which authorize and control the abstraction of water by cities, districts and state agencies; and, quite recently, statutes controlling private uses for the protection of minimum flows and environmental values. In most "riparian states" these statutes rather than common law are the important features of modern water law.

8.9 CONCLUSIONS

From the review of the information collected on the major laws that exist nationwide with regard to the use and consumption of water, the following conclusions may be drawn:

1. There is no simple way to set down all the differing laws and accompanying rules and regulations, since they vary from state to state and are at the bottomline subject to decisions of the courts. An attempt was made to show the constraints on the legal availability of water. These constraints form a complex web which involves Federal rights, Indian rights, state rights, riparian rights, appropriation rights, beneficial uses, international treaties and others. Disregard for or any attempt to abrogate these rights (or arrangements) is certain to meet with serious objections and may result in lengthy litigation.

2. The fact that no comprehensive body of law exists, either on national or state level on the regulation and consumptive use of water, adds to the difficulties and quandary in understanding water rights. This is to say that present national and state laws and regulations need codification as well as in some cases to be rewritten to meet our present societal needs.

3. State boundaries seldom coincide with hydrologic boundaries, therefore instances exist where two or more legal systems act to manage or allocate water from one integrated source. These conflicts have and are being resolved by interstate compacts, federal legislation and by Supreme Court decisions.

4. The diversity of state laws can be attributed to the variety of hydrologic conditions in the country. These range from areas of water abundance to those of complete scarcity. Primacy of state systems for legal remedy and allocation would seem to reflect most accurately these local conditions.

5. There is a trend toward increased federal involvement in order to attain uniform national goals for energy and water resource management. This trend may continue in order to override long standing and powerful local political interests.

6. Water quantity and quality although seemingly intertwined physically have not been treated in combination legislatively. This is true both at the state and federal level, making water resource management all the more difficult.

7. Most Federal water resource programs include subsidies which lower the price of water to users below what it actually costs to provide the water. The average price of water from Federal projects and programs are approximately 20 to 30 percent of actual cost to provide the water. As a result, users take more water than they would if the price were higher.

8. Due to the great diversity of the United States water resources systems, it would be difficult for a single entity to be used to integrate the activities of all water agencies. Differences in state water laws, water uses and supply conditions have created regulations that seem all but impossible to integrate.

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TABLE 8-1

COMPACTS, TREATIES AND REGULATIONS FOR
MAJOR RIVERS AND LAKES IN THE UNITED STATES

Region	River/ River Basin	Compact/Treaty/Regulation	Minimum Flow Requirement at the Outflow Point (Million Gallons/Day)			Apportionment
			1975	1985	2000	
01 New England	Merrimack	Merrimack River Flood Control Compact, 1956				MA, NH
	Connecticut	Connecticut River Flood Control Compact, 1951				MA, CT, NH, VT
02 Mid-Atlantic	Delaware	Delaware River Basin Compact, 1961	1131	1131	1131	DE, NJ, NY, PA
	Hudson					
	Susquehanna	Susquehanna River Basin Compact				
	Potomac	Potomac River Compact				MD, WV, PA, VA, DC
03 South Atlantic-Gulf	Tombigbee Alabama Apalachicola					
04 Great Lakes	Eastern Lake Erie		64500	64500	64500	
	Great Lakes	Great Lakes Basin Compact, 1955				IL, IN, MI, MN, NY, OH, PA, WI
	Niagara River	Niagara River Water Diversion Treaty, 1950				Canada - United States
05 Ohio	Ohio Wabash					
06 Tennessee	Cumberland Tennessee					
07 Upper Mississippi	Upper Mississippi Illinois					
08 Lower Mississippi	Lower Mississippi					

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TABLE 8-1 (cont'd.)

Region	River/ River Basin	Compact/Treaty/Regulation	Minimum Flow Requirement at the Outflow Point (Million Gallons/Day)			Apportionment
			1975	1985	2000	
09 Souris-Red Rainy	Red River	Red River of the North Compact, 1937				SD, ND, MN
	Yellowstone River	Yellowstone River Compact, 1950				MT, ND, WY
	Lake of the Woods	Lake of the Woods Convention, 1925				Canada - United States
	Rainy Lake	Rainy Lake Convention, 1938				Canada - United States
10 Missouri	No/So Platte		78	78	78	
	Kansas		34	34	34	
	Belle Fourche	Belle Fourche River Compact, 1943				SD (90%), WY (10%)
	Republican	Republican River Compact, 1942				CO, KS, NE
	South Platte	South Platte Compact				CO, NE
	St. Mary & Milk Rivers	Canadian Boundary Water Treaty, 1909				Canada - United States
11 Arkansas White-Red	Upper Arkansas	Arkansas River Compact (1948)	808	808	808	CO, KS
	• Red	Arkansas River Basin Compact, 1965				KS, OK
	Canadian River	Canadian River Compact, 1950				NM, TX, OK
12 Texas-Gulf	Pecos River	Pecos River Compact, 1948				NM (57%), TX (43%)
	Sabine River	Sabine River Compact, 1953				TX, LA
13 Rio Grande	Middle		54	54	54	
	Rio Grande	Rio Grande River Compact, 1938				CO, NM, TX
	Costilla Creek	Costilla Creek Compact, 1963				CO, NM
	LaPlata River	LaPlata River Compact				CO, NM
	Rio Grande, Colorado, Tijuana	Rio Grande, Colorado and Tijuana Treaty, 1944				United States - Mexico
14 Upper Colorado	Upper Colorado	Upper Colorado River Basin Compact, 1948				AZ, CO. NM, UT, WY
	San Juan		6700	6700	6700	
	Bear	Bear River Compact, 1955				WY, UT
	Colorado	Colorado River Basin Compact, 1922				UT, WY, CO, NV, NM, CA
15 Lower Colorado	Lower Colorado Main Stem		1340	1340	1340	
16 Great Basin						

TABLE 8-1 (cont'd.)

Region	River/ River Basin	Compact/Treaty/Regulation	Minimum Flow Requirement at the Outflow Point (Million Gallons/Day)			Apportionment
			1975	1985	2000	
17 Pacific North-west	Snake River Columbia River	Snake River Compact, 1949 Columbia River Cooperative Development Treaty, 1961				ID (96%), WY (04%) Canada - United States
18 California	Klamath River	Klamath River Basin Compact, 1957				CA, OR

NOTES:

1. Where the apportionment of a river or lake between states or countries has not been specifically designated or the division is too complex to be cited on this Table, the full text of the compact or treaty can be found in Documents on the Use and Control of Waters of Interstate and International Streams, 2nd Edition, Witmer, T. R., ed, House Document 319, 90th Congress, 2nd Session, U.S. Government Printing Office, Washington, 1968.
2. Minimum Flow Requirement for various rivers indicated on the chart are taken from the preliminary draft of The Nation's Water Resources, The Second National Assessment by the U.S. Water Resources Council.
3. Apportionment section shows states involved in compact or treaty dividing the waters specified. Where a percentage apportionment is given, it is indicated after the name of the State.
4. Rivers are listed either due to their size and importance or to fact that a treaty or compact exists.

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